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FORECAST OF REMOTE UNDERWATER SENSING TECHNOLOGY.(U)

JUL 80 V A DEL GROSSO, P B ALERS MIPR-Z70099-9-94080

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Forecast of Remote Underwater Sensing Technology

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16. Abstract

A report has been prepared for the United States Coast Guard which develops 10-year and 25-year forecasts of the evolution of underwater remote sensing system technologies. Included is a delineation of the status of those technologies identified as having present or potential utility to current and projected Coast Guard missions. A modified Delphi technique was utilized to develop the forecasts wherein 131 questionnaires dealing with 9 specific technologies were sent to 56 separate organizations. The final positive response exceeded 50%.

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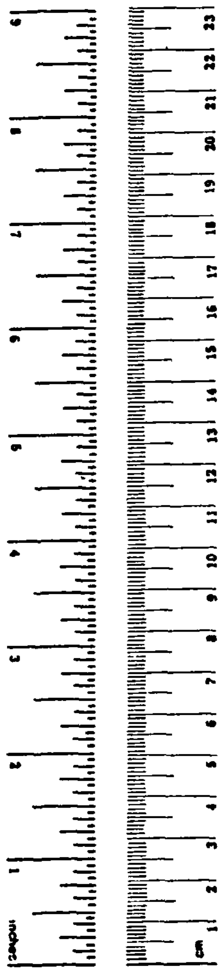
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

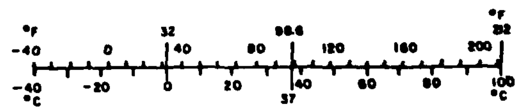
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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CHAPTER 1 - EXECUTIVE SUMMARY

The main purposes of this report are: (1) The delineation of the current status of underwater remote sensing system technologies identified as having present or potential utility to current and projected U.S. Coast Guard missions; and (2) the development of 10 year and 25 year forecsts of the evolution of these technologies. A narrative discussion is presented in Chapter 4 of seven broad technological categories encompassing these systems, viz., ACOUSTIC, OPTICAL, MAGNETIC, ELECTRIC FIELD, ELECTROMAGNETIC (Miscellaneous), CHEMICAL, and FIBER OPTIC. These are further divided into 27 specific categories which are described in sufficient detail to permit familiarization with their individual promises and problems.

The technological categories covered by this report are as follows:

A. OBSTACLE AVOIDANCE SONAR

B PORTABLE (HAND HELD) SONAR

C MILITARY SONAR

D SIDE SCAN SONAR

E MAPPING (MULTI-BEAM) SONAR

F SYNTHETIC APERTURE SONAR

G PARAMETRIC SONAR

H ACOUSTICAL IMAGING/HOLOGRAPHY

I ACOUSTICAL POSITIONING/NAVIGATION

J ACOUSTIC COMMUNICATION

K ACOUSTIC BOTTOM PROFILING

L ACOUSTIC SUB-BOTTOM PROFILING

M ACOUSTIC ENVIRONMENTAL

N OPTICAL DETECTION/LIDAR

O OPTICAL IMAGING - AREAL

P OPTICAL IMAGING - RANGE GATING

Q OPTICAL IMAGING - SCANNING

R OPTICAL COMMUNICATION

S OPTICAL ENVIRONMENTAL

T MAGNETIC

U ELECTRIC FIELD

V ELECTROMAGNETIC/ENVIRONMENTAL

W ACOUSTIC BUOYS

X ACOUSTIC ARRAYS

Y ACOUSTIC PROCESSORS AND BEAMFORMERS

Z CHEMICAL

AA FIBER OPTICS

A representative listing of some 170 currently available underwater remote sensing systems is offered in Chapter 5, which includes equipment and the manufacturer, the basic specifications, and the approximate current acquisition cost.

The several appendices include a tabulation of personal contacts in the 88 listed organizations along with addresses and phone numbers. A bibliography of 152 entries has been designed to facilitate development of a more comprehensive knowledge of the various technologies, if so desired.

Although the foregoing has obvious value, the forecasts are considered to be the most valuable part of this report. A modified Delphi approach was used for the following categories for which forecast questionnaires were prepared and sent to 56 separate organizations (131 questionnaires in total):

A, B, D/E, I, J, K, L, O/P/Q, and T.

Questionnaires were not prepared for the remaining categories either because they are used primarily for military applications, viz., C, F, G, R, W, X, and

Y, or they are considered mature, or only a few organizations are currently involved in them. The actual questionnaires are reproduced as Appendix B, while Chapter 6 presents the replies and offers a "consenus." The several questionnaires had respondents as follows:

A	- 7
B	- 4
D/E	- 11
I	- 15
J	- 5
K	- 9
L	- 7
O/P/Q	- 7
T	- 2

The "consensus" weighted with the authors' current best estimate can be abstracted as shown in Table 1.

It is not surprising that acoustics has been, is now, and most certainly will be the most useful underwater remote sensing technology. It seems to offer the best comprise between range and range resolution. The former can be increased simply by using a lower basic frequency while the latter is enhanced by utilizing a large bandwidth signal. Lateral resolution can be dramatically improved either by employing narrow angle beams generated by non-linear or parametric sonar, or by more sophisticated post-detection processing. Examples are those used in synthetic aperture techniques, the processing of seismic signals in petroleum exploration, or even computerized axial tomography (CAT) scanning.

Table 1. Consensus of replies to questions asked for selected technological categories, as of the present, the year 1990, and the year 2005.

A. ACOUSTIC - DETECTION - OBSTACLE AVOIDANCE SONAR (7 Replies)

Q. What will be maximum range, range resolution, angular resolution?

		PRESENT	1990	2005	
A.	Range	0.75	1.2	2.5	kilometers
	Range resolution	10.	5.	2.5	meters
	Angular resolution	1.	0.75	0.5	degrees

Q. At range of 200 meters, what will be range resolution, angular resolution?

A.	Range resolution	2.5	1.0	0.5	meters
	Angular resolution	1.	0.75	0.5	degrees

B. ACOUSTIC - DETECTION - PORTABLE (HAND-HELD) SONAR (4 Replies)

Q. What will be maximum range, area of smallest detectable object?

A.	Range	0.15	0.2	0.5	kilometers
	Detectable object	5.	2.5	1.	square meters

Q. At range of 100 meters, what will be area of minimum detectable objects?

A.	Area	5.	2.5	0.5	square meters

D/E ACOUSTIC - IMAGING/MAPPING - SCANNING (11 Replies)

Q. What will be maximum slant range, resolution, tow speed, swath width for commercial side scan sonars?

A.	Slant range	0.75	1.25	1.75	kilometers
	Resolution	2.5	2.5	1.	meters
	Tow speed	10.	15.	20.	knots
	Swath width	1.5	1.75	2.5	kilometers

I. ACOUSTIC POSITIONING (15 Replies)

Q. For a short baseline system/1 bottom transponder, what will be maximum slant range, range resolution, bearing resolution?

		PRESENT	1990	2005	
A.	Slant range	5.	7.5	10.	kilometers
	Range resolution	5.	2.5	1.	meters
	Bearing resolution	2.	1.	0.5	degrees

Q. For same system at 1 km range, what range resolution, bearing resolution?

A.	Range resolution	1.	0.5	0.25	meter
	Bearing resolution	1.	0.75	0.25	degrees

Q. For a long baseline system/4 bottom transponders in square/1 km depth, what will be maximum usable edge of square, postion resolution?

A.	Edge spacing	7.5	10.	15.	kilometers
	Position resolution	2.	1.5	1.	meters

Q. As above, for 2x2 km square:

A.	Position resolution	1.	1.	0.5	meters

J. ACOUSTIC - COMMUNICATION/TELEMETRY (5 Replies)

Q. What will be maximum range, bandwidth?

A.	Range	7.5	10.	20.	kilometers
	Bandwidth	1.	5.	10.	kilohertz

Q. At 1 kilometer range, what will be bandwidth?

A.	Bandwidth	7.5	15.	20.	kilohertz

K. ACOUSTIC - ENVIRONMENTAL - BOTTOM PROFILING (9 Replies)

Q. What will be maximum range, vertical resolution, ship speed for surface units?

		PRESENT	1990	2005	
A.	Range	5.	10.	15.	kilometers
	Vertical resolution	2.5	1.	0.5	meters
	Ship speed	15.	17.5	20.	knots

Q. Similarly, for deep-towed units?

A.	Altitude resolution	0.5	0.1	0.05	meters
	Depth resolution	1.	0.1	0.05	meters
	Ship speed	3.5	5.	10.	knots

L. ACOUSTIC - ENVIRONMENTAL - SUB-BOTTOM PROFILING (7 Replies)

Q. What will be maximum altitude, bottom penetration, resolution for commercial profilers?

A.	Altitude	0.5	1.	2.	kilometers
	Penetration	0.35	0.5	0.75	kilometers
	Resolution	50.	50.	25.	centimeters

Q. For 100 meter penetration what will be resolution, tow speed, layer resolution, detectable impedance change?

A.	Resolution	35.	15.	7.5	centimeters
	Tow speed	5.	7.5	15.	knots
	Resolvable layer	20.	10.	5.	centimeters
	Impedance change	5.	3.	0.3	percent

O/P/Q. OPTICAL - IMAGING - AREAL/RANGE GATING/SCANNING (7 Replies)

Q. What will be maximum usable altitude, area coverage, resolution for deep ocean film camera system?

		PRESENT	1990	2005	
A.	Altitude	35.	75.	150.	meters
	Area rate	0.75	7.5	15.	sq. km/nr
	Resolution	20.	5.	2.	centimeters

Q. Similarly, for a quasi-real-time TV system?

A.	Altitude	35.	75.	150.	meters
	Area rate	0.5	7.5	15.	sq. km/hr
	Resolution	50.	10.	5.	centimeters

Q. What will be maximum angular resolution for film, TV?

A.	Film	0.5	0.35	0.2	milliradians
	TV	3.5	1.5	1.	milliradians

Q. What will be area coverage rate for color imaging?

A.	Coverage	3500.	10,000.	25,000.	sq. meters/hr

T. MAGNETICS (2 Replies)

Q. What will be sensitivities of fluxgate, proton, optical pump, SQUID (superconducting) magnetometers?

A.	Fluxgate	0.1	0.03	0.03	nanotesla
	Proton	0.01	0.003	0.003	nanotesla
	Optical pump	10^{-3}	10^{-5}	10^{-5}	nanotesla
	SQUID	10^{-5}	10^{-7}	10^{-7}	nanotesla

It is anticipated that correlation techniques presently utilized by the military will be applied to commercial passive sonar augmented by acousto-optics. Active sonar, however requires a major breakthrough in transducer technology to permit cost effective improvements in commercial applications. These include, besides detection, bottom and sub-bottom mapping by multi-beam side-looking sonar, and acoustic positioning and communication.

Optics plays a secondary, yet major role in remote underwater sensing systems. Light does not have the penetration power of sound, nor does it offer the maximum ranges of active acoustics, nor the utility of passive underwater detection. It does, however promise superior classification and identification at moderate ranges by optical imaging. To fulfill this promise a combined range-gated, synchronous-scanned imaging system needs development, along with improved blue-green lasers. The latter is under current development and the former is presently technologically feasible. The second application of optics to remote underwater sensing is in the field of air-to-submarine communications. Laser links between overhead platforms and submarines have been considered by the Navy, but it is not clear whether such a system or an extremely-low-frequency (ELF) electromagnetic communication system will be used in the future.

It is interesting that the ELF system proposes use of a super-conducting quantum interference device (SQUID) detector as an extremely low noise electromagnetic field detector. Beyond the detection of magnetic anomalies for search, this communication application appears to be the only other use of magnetics as a remote underwater sensing system.

CHAPTER 2 - SCOPE AND DEFINITIONS

The purpose of this study is two fold: (a) To establish the current status of underwater remote sensing systems (including sensor transducers, data processing equipment, and information transmission and display equipment) and (b) to develop a forecast of the evolution of these underwater remote sensing technologies in two separate time frames, 1980-1990 and 1990 - 2005. Those technologies which should be of direct benefit to the United States Coast Guard are emphosized, but the study is not limited to only these technologies since the current mission requirements for the Coast Guard will almost certainly change over the course of the next 25 years.

Within the scope of this study an underwater remote sensing technology is defined as one in which either: a) water itself is a part of the information transmission channel for the phenomenon being sensed; or b) the specific object of interest is located beneath the water surface. Specifically excluded are sensing technologies which are physically located outside the boundaries of the water environment and which are employed to sense phenomena or objects which originate at or above the water surface. Thus sensor systems which are physically located outside the boundaries of the water environment and are used to sense phenomena originating underwater are included in this study. The platforms for these systems may include surface buoys, bottom and water column moorings, submersibiles, ships, and planes.

It should be noted that real-time or quasi-real-time systems only are considered, and no systems requiring subsequent "laboratory" analysis of recovered samples are included.

Satellite sensing systems are excluded because of the limited capabilities of such systems directly to sense "underwater" phenomena and because of

the very sensitive (from the standpoint of security) nature of the data concerning such systems.

Thus we exclude for tne reasons above satellite obseravations, dredging, drilling and sample collection for subsequent analysis.

CHAPTER 3 - STUDY HISTORY

In order to establish an initial baseline for actual and potential Coast Guard needs and requirements in the underwater remote sensing area, several Coast Guard documents and reports were reviewed. From these (primarily CG411, Planning and Programming Manual), the Coast Guard Operating Programs which could potentially benefit through the use of underwater remote sensing systems were identified. These programs include:

TABLE 3-1: COAST GUARD OPERATING PROGRAMS WHICH HAVE POTENTIAL UNDERWATER SENSING REQUIREMENTS

AN	- (Short Range) Aids to Navigation
BA	- Bridge Administration
CVS	- Commercial Vessel Safety
ELT	- Enforcement of Laws and Treaties
IO	- Ice Operations
MEP	- Marine Environmental Protection
MO/MP	- Military Operations/Preparedness
MSA	- Marine Science Activities
PSS	- Port Safety and Security
RBS	- Recreational Boat Safety
SAR	- Search and Rescue

Two current Coast Guard programs that have been omitted as having no perceived requirements for remote underwater sensors are RA (Radionavigation Aids) and RT (Reserve Training).

For each program which did have a perceived need, specific requirements were obtained through a more detailed analysis of current and anticipated Coast Guard missions. Table 3-2 lists these specific requirements by program.

TABLE 3-2: SPECIFIC COAST GUARD UNDERWATER SENSING REQUIREMENTS BY PROGRAM

AN	- Underwater Markers for Buoy Relocation
	- Underwater Communication
	- Underwater Navigation
	- Diver/Swimmer Orientation
	- Polar Commercial Channel Marking
	- Underwater Hazard Location
BA	- Underwater Structure Inspection
CVS	- Submersible Inspection
	- Hull Inspection
	- Offshore Platform Inspection
	- Underwater Structure Inspection
	- Underwater Pipeline Inspection
ELT	- Submersible Detection
	- Diver/Swimmer Detection
	- Fisheries Surveillance
	- Undersea Mining Surveillance
	- Underwater Inspection
	- Pollution Monitoring
IO	- Polar Commercial Channel Marking
	- Ice Measurement
MEP	- Pollution Monitoring
	- Underwater Inspection
MO/MP	- Antisubmarine Warfare
	- Undersea Warfare
MSA	- Submerged Phenomena Investigation
	- Sea Ice Measurement
	- Ocean Sounding
PSS	- Underwater Buried Object Detection
	- Submersible Detection
	- Diver/Swimmer Detection
RBS	- Hull Inspection
	- Submersible Inspection
SAR	- Diver/Swimmer Location
	- Underwater Communication

The system capabilities describing the above specific requirements can be cataloged as: (a) navigation/marking/orientation, (b) search/surveillance/detection, (c) classification/identification, (d) communication/information transfer, (e) measurement/monitoring.

Technologies relevant to these system capabilities encompass acoustic, biological, chemical, electromagnetic, mechanical (the latter including particle effects such as motion, heat, and pressure), nucleonic and optical. A matrix of these broad technological areas categorized as Acoustic, Optical, Magnetic, Electric Field, Electromagnetic, Biological, Mechanical, Nucleonic, and Chemical was prepared against the U. S. Coast Guard missions as indicated in Table 3-3.

Next a historic data base was established, and a list of significant developers was compiled primarily through a literature survey. The major source of information was the technical literature, principally reports of the 1979 IEEE Oceans Symposium and programs of 1979 meetings of the Marine Technology Society, the SPIE Ocean Optics VI, the Offshore Technology Conference, the Acoustical Society of America, and the Conference on Lasers and Engineering Applications. Trade periodicals, including Sea Technology, Ocean Industry, and Laser Focus were searched for relevant articles or advertisements. Finally, search was made of DDC documentation of both relevant reports and Independent Research and Developments efforts by DoD contractors as well as NTIS documentation of groups receiving pertinent support by non-DoD Agencies.

These all contributed to the list of companies, universities, and laboratories that were contacted, initially by mail, to confirm their significant involvement in the development of underwater remote sensing systems. Some 300 general letters (Appendix A) were sent out initially not only requesting

information on currently available systems but also soliciting later contributions to the trend identification and forecast. Of the initial 278 organizations contacted, 96 responded with information pertinent to the study, 93 responded negatively, and 89 did not respond.

As the responses to these general information letters were received, it became apparent that the sensor technology categories of Table 3-3 could be further refined as indicated in Table 3-4. It should be noted in this list that the categories BIOLOGICAL and MECHANICAL have been omitted. The BIOLOGICAL category was omitted because this technology is being covered by an entirely separate U. S. Coast Guard study. The category MECHANICAL was omitted because of current investigations by the U. S. Geological Survey.

Most of the items in this final tabulation of categories are self-explanatory, but some comments are in order. It is necessary to differentiate between military sonars and those developed specifically for commercial civilian application and use. The category ACOUSTIC-ENVIRONMENTAL is composed of acoustic flow (or current) meters and sound speed sensors. OPTICAL-ENVIRONMENTAL is mainly fluorometry which could be considered in the CHEMICAL category; the latter however includes only a single petroleum "sniffer." ELECTRIC FIELD is confined to communication by this means. ELECTROMAGNETIC is a near miscellaneous category composed mainly of environmental sensors not employing either acoustics or optics. OPTICAL COMMUNICATION is wholly submarine-to-air laser communication.

Finally, it is noted that the alphabet has been filled in by inclusion of categories W, X, and Y and AA which appear to be out of sequence. The reason for this is their late addition to the list and a desire to avoid recataloging the extensive files previously developed.

TABLE 3-3: SENSOR TECHNOLOGY UTILIZATION BY COAST GUARD PROGRAM

	ACOUSTIC	OPTICAL	MAGNETIC	ELEC. FIELD	ELECTRO-MAGNETIC	BIOLOGICAL	MECHANICAL	NUCLEONIC	CHEMICAL
AN	X	X	X	X		X			
BA	X	X	X				X		
CVS	X	X	X	X			X		
ELT	X	X	X	X		X			
IO	X	X		X					
MEP	X	X				X		X	X
MO/MP	X	X	X	X		X			
MSA	X	X	X		X		X	X	X
PSS	X	X	X	X		X			
PBS	X	X	X	X			X		
SAR	X	X	X	X		X			

TABLE 3-4: TECHNOLOGICAL CATEGORIES UTILIZED IN THIS FORECAST

A	OBSTACLE AVOIDANCE SONAR
B	PORTABLE (HAND HELD) SONAR
C	MILITARY SONAR
D	SIDE SCAN SONAR
E	MAPPING (MULTI-BEAM) SONAR
F	SYNTHETIC APERTURE SONAR
G	PARAMETRIC SONAR
H	ACOUSTICAL IMAGING/HOLOGRAPHY
I	ACOUSTIC MAPPING/POSITIONING/NAVIGATION
J	ACOUSTIC COMMUNICATION
K	ACOUSTIC BOTTOM PROFILING
L	ACOUSTIC SUB-BOTTOM PROFILING
M	ACOUSTIC ENVIRONMENTAL
N	OPTICAL DETECTION/LIDAR
O	OPTICAL IMAGING - AREAL
P	OPTICAL IMAGING - RANGE GATING
Q	OPTICAL IMAGING - SCANNING
R	OPTICAL COMMUNICATION
S	OPTICAL ENVIRONMENTAL
T	MAGNETIC
U	ELECTRIC FIELD
V	ELECTROMAGNETIC/ENVIRONMENTAL
W	ACOUSTIC BUOYS
X	ACOUSTIC ARRAYS
Y	ACOUSTIC PROCESSORS AND BEAMFORMERS
Z	CHEMICAL
AA	FIBER OPTIC TECHNOLGY

Once the answers to the general survey letter had been received and the final listing (Table 3-4) of technological categories had been compiled, the forecast effort was initiated. The forecasting techniques relied heavily upon a modified Delphi approach in order to predict the future capabilities of each technology. Ten categories (as indicated in Table 3-5) were considered the most suitable for this type of predictive method because of their relatively high potential for Coast Guard use and because the replies to the general survey letter showed that for these categories at least three (and as many as thirteen) separate organizations were actively involved in development work.

TABLE 3-5: CATEGORIES FOR WHICH FORECAST QUESTIONNAIRES WERE PREPARED

A. OBSTACLE AVOIDANCE SONAR
B. PORTABLE (HAND HELD) SONAR
D. SIDE SCAN SONAR
E. MAPPING (MULTI-BEAM) SONAR
I. ACOUSTIC POSITIONING
J. ACOUSTIC COMMUNICATION
K. ACOUSTIC BOTTOM PROFILING
L. ACOUSTIC SUB-BOTTOM PROFILING
O/P/Q. OPTICAL IMAGING - AREAL/RANGE GATING/SCANNING
T. MAGNETIC

Separate questionnaires (Appendix B) were prepared for each of the categories listed in Table 3-5 and were distributed to the most appropriate organizations identified during the initial phases of this study. A total of 131 questionnaires in 9 categories (note that categories D and E were combined into a single questionnaire) were sent to 56 separate organizations. A total of 70 positive responses were received from 29 organizations. Only 15 organizations failed to respond; these accounted for 30 questionnaires. 16 organizations returned 31 questionnaires they chose not to answer.

The remaining 16 categories in Table 3-4 were not considered amenable to the Delphi forecasting approach for a variety of reasons. Categories C, F, G, R, W, X, and Y are currently used primarily for military applications and a significant portion of the data concerning these technologies is classified SECRET or above. Consequently, any Delphi approach to predict the future capabilities of these technologies would have involved a more lengthy and restrictive process than that employed for any unclassified technology. Such a process probably would have exceeded the time and manpower available for this effort and in addition may have resulted in a product which exceeded the security classification of this study.

The remaining categories in Table 3-4 were either considered to be mature (in which case little or no technological growth is expected) or only a few organizations were actively involved in the technological area. In either case, a Delphi analysis would not have been justified. Although no formal Delphi analysis was conducted for these technologies, a "best estimate" attempt has been made to predict the future performance parameters of these technologies based on the authors' own experience and communications with individuals who are actively involved in these areas.

CHAPTER 4 - DISCUSSION OF TECHNOLOGIES

This section contains a narrative-form discussion of the technologies A through AA. They are introduced by a general discussion of the major categories.

4.1 ACOUSTICS - During WWI, passive audio frequency listening gear was the only underwater acoustics system in use. Active sonar systems were later developed by the Naval Research Laboratory (NRL); in particular the QB sonar with a range of 10 kyd was developed at NRL in 1934. Sonar is an acronym for Sound Navigation and Ranging which indicates the original purpose of these active acoustic underwater systems. It is interesting that the term sodar has come into use by laboratory investigators using the sonic version of radar (an acronym for radio detection and ranging).

The principle of active sonar is deceptively simple. A burst of sound is transmitted, and its reflection from an object is detected. From this, assuming some directionality for the source or receiver plus some knowledge of the speed of sound in the water medium, the range and bearing of the target can be determined. In reality, the work in the early 1930's was handicapped by inadequate knowledge of the medium, in particular the bending of sound rays by gradients and fluctuations of temperature, salinity and pressure. Today, of course, sound channels (both surface and deep), shadow zones, convergence zones, etc., are predictable by the use of in-situ sensors which measure either sound speed directly or the parameters on which it depends.

The speed of sound in water is effectively independent of frequency. Its aborption, however, is directly dependent on the square of the frequency except for an inflection near 100 kHz due to the $MgSO_4$ relaxation effect and a smaller inflection near 1 kHz due to $B(OH)_3$ relaxation. Thus the range expected for an active acoustic system is dependent on frequency as well as output power and receiver sensitivity. An additional sound propagation loss is

due to goemetric spreading from a point source describable as either spherical spreading in an (almost) unbounded isotropic medium or as cylindrical spreading in an acoustic channel (waveguide).

The receiving sensitivity of modern hydrophones is generally environmental-noise-limited. To minimize flow noise, sonar domes were developed about 1935 at NRL, and towed arrays were later developed to remove the hydrophone from the ship's self-generated noise.

The cavitation threshold of the water medium limits the power output of an acoustic (pressure) source. This threshold increases slightly with depth but is limited to about 1 watt/cm^2 for shallow sources. Thus an increase in output power can be achieved only by an increase in the radiating area of the source. This introduces the remaining parameter of directivity. As the source becomes larger its output beamwidth decreases as λ/D where λ is wavelength and D is the lateral dimension of the source. This beamwidth is for the main lobe only; unfortunately side lobes develop which increase in number and intensity as the ratio λ/D increases, so for truly narrow beams, sophisticated mechanical or electrical configurations or later signal processing is required. It is possible to reduce the apparent beam width by utilizing synthetic aperture techniques whereby the effective source aperture is essentially the width of the real beam at the target. In another approach, parametric sonar utilizes the non-linear interaction of overlapping primary beams from small physical aperture sources to create a low frequency narrow beam with no side lobes. These technologies are discussed in greater detail in the sections devoted to them.

4.1.1 Category A. OBSTACLE AVOIDANCE SONAR

As the name implies, this category includes non-military sonars with minimal beamwidths for source and/or receiver hydrophones. These are generally aimed in the direction of advance of the vessel or platform on which the sonar is mounted. The beam is also generally depressed at some angle below the horizontal to minimize surface interference. Some mechanical or electronic provision for sweeping the beam azimuthally is considered essential and the transducer may be stabilized. The display may include full 360° scan, sector or other scans with some modifications such as zoom or offset and even a range window or target lock-on. Another scan might be the simple A scan where the abscissa is time (or range) and the ordinate is some value proportional to the strength of the echo return. A crude acoustic image might be presented by a B scan which is simply an orthogonal X and Y coordinate presentation of the usual r and θ coordinate sector scan. That is, instead of presenting the data as intensity modulation in two-dimensional space characterized by angle and range, the display coordinates are off-track distance and forward range. It will be noted later that these sonars can also be employed as single side-scan sonars with the beam fixed at a right angle to the track. In this case range is measured athwartship, that is, along each individual plus or the trace thereof, while successive traces are displaced in proportion to the sonar platform forward advance.

The sonar output is usually a time gated pulse, but a frequency modulated continuous transmission is also employed. This latter results in increased frequency bandwidth and improved range resolution. More detail is included in the synthetic aperture sonar discussion.

Operating frequencies range from 25 kHz to 500 kHz. Maximum ranges are from 100 m to 500 m. The horizontal beamwidths employed are generally in the

range of 2° to 12° while vertical beamwidths may be found from 2° to 65°. These sonars are usually hull mounted and are often retractable for equipment safety. In very few instances is compensation for beam attenuation and/or spreading loss even attempted. A relatively unsophisticated method of undertaking this is to employ Time Variable Gain (TVG) which simply adjusts receiver gain as some predetermined or preselected function of time, usually linearly between two limits. This partial compensation preferentially amplifies those echoes originating at greater ranges. It is obviously possible to employ more sophisticated circuitry for other compensations.

4.1.2 Category B. PORTABLE (HAND-HELD) SONAR

These sonars are small, sometimes neutrally buoyant, units which emit a sound pulse in the direction in which they are manually aimed. Operating frequencies are in the range of 100-200 kHz. Some units employ continuous-transmission frequency-modulation rather than pulse modulation. The active mode can have operating ranges in the order of 100 m while a passive mode might be capable of picking up pingers at 1000-2000 m. Read out techniques may vary from a simple audio tone produced in earphones with the tone frequency varying with range, to more sophisticated video screen displays of pulse travel time.

4.1.3 Category C. MILITARY SONAR

This category was originally intended to consist of those military sonars used for detection and/or classification. Obviously, fire-control sonar is not included, nor are details of the many Navy systems to be found in this unclassified report. Other military acoustic systems are discussed briefly under the more specific categories of mapping (multi-beam) sonar, synthetic aperture sonar, parametric sonar, and acoustic communication. Specific examples of these, including AN designation if applicable, are included here for

completeness. Working parameters cannot be stated in this report, so there is also no inclusion of these military systems in Chapter 5 "Representative Current Systems" which tabulates specifications along with manufacturer and cost.

With no intent to tout any system, it appears useful to quote from some of the avowedly promotional material for selected sonar systems.

The AN/SQS-26/53 is described as the "world's most advanced surface sonar equipment." It is certainly the "free world's largest active sonar system." Indeed this sonar consists of 37 cabinets of electronics and a cylindrical transducer array of 576 elements weighing over 40 tons (in air). The general contractor is General Electric Company (Syracuse), and an estimated cost per system is 15.4 million dollars. A 53 Improvement Program utilizing the AN/UYS-1 digital acoustic processor has been assigned to Hughes. The 26/53 sonar operates in three active modes: bottom bounce, convergence zone, and surface duct. It can also operate simultaneously in a passive mode.

The AN/SQR-19 is "the world's most advanced surface ship towed array sonar system." This passive, stand-alone, tactical towed array sonar (TACTAS) is under development with General Electric Company as prime contractor. "Tactical" signifies no reduction in ship speed for deployment. The system has an estimated cost of 7.5 million dollars. Software is being implemented for the AN/UYK-20, Proteus Advanced Signal Processor (ASP); the display console is shared with LAMPS (Light Airborne Multi-Purpose System). This latter is an integrated ship/aircraft weapon system "capable of detecting, classifying, locating, and destroying enemy vessels over thousands of miles of ocean." LAMPS' major contractors include Sikorsky, IBM (Federal System Division), and General Electric (Military Engine Division).

While the 19 TACTAS is to be capable of looking in all directions all the time, its fallback, the AN/SQR-18 (TACTAS) is not. This latter is called BOW-LEGS when operated without a depressor. The 18 is normally deployed from the

AN/SQS-35 Variable Depth Sonar (VDS). Its cost is estimated at 1.5 million dollars, and Edo-Western is prime contractor.

Probably "the most advanced high performance digital sonars in the Navy" are the AN/BQQ-5 (SSN sonar) and AN/BQQ-6 (SSBN sonar) whose costs are estimated at 14 million and 20 million dollars respectively. The AN/BQQ-5A (Phase I, II, and III) are improvements of the Q-6. These sonars include hull-mounted and towed arrays, and signal processing is implemented on AN/UYK-7 general purpose digital computers.

The last search sonar to be mentioned here is the AN/SQS-56 used in FFG-7 class ships. This has an estimated procurement cost of 2.5 million dollars and is a hull mounted, active and passive, search, detection, classification, localization, and tracking sonar having direct path and surface duct capabilities. It is a product of Raytheon Corporation (Submarine Signal Division).

Bottom profilers or depth sounders include the AN/BQN-3 and 3J manufactured by General Electric Corporation under subcontract to Sperry Rand Corporation. These are used for POLARIS and TRIDENT SSBN's. A parametric sonar bottom profiler is used in SSN's and is designated AN/BQN-17. Estimated cost is 300 thousand dollars. A more general bottom profiler is the AN/UQN-4 sonar sounding set manufactured by Edo-Western Corporation and listing for 25 thousand dollars. This is also designated their model 9057.

Besides the parametric sonar bottom profiler mentioned above, another parametric unit is designated simply as "special purpose sonar" and is used for communication. A more general communication sonar is the AN/WQC-5 developed by Spectral Dynamics with improved range over the WQC-2A. This unit costs between 60 and 85 thousand dollars.

Military mapping (multi-beam) sonars include SASS and BOTOSS. The latter is designated AN/SQN-17 and has an estimated cost of 5 million dollars. A little more detail is found in Category E. The AN/SQS-14 is a helicopter towed bottom scanning high resolution multi-beam active minehunting sonar. Synthetic aperture buried mine sonar development is in progress at Westinghouse Electric Corporation and at Naval Coastal Systems Center (NCSC). A candidate is designated AN/AQS-14.

Parametric sonar is also under development for buried mine detection. Work under way includes the Buried Object Detection System (BODS) sonar at the University of Texas and the Buried Mine Sonar (BURMS) at NCSC.

Finally, mention should be made of environmental acoustic systems such as the AN/BQH-1B Sound Speed-Depth Measuring Set.

4.1.4. Category D. SIDE SCAN SONAR

The operating principle of Side Scan Sonar is essentially the same as Obstacle Avoidance Sonar, and as noted, many such sonars can be employed as a Single Side Scan. In Dual Side Scan Sonar an acoustic beam is radiated from both sides of the vehicle or towed platform. The important feature of each beam is that it is very narrow (typically 1° or 2°) in the horizontal plane while adequately broad (typically 20° to 50°) in the vertical plane, so that, with the main axis of the beam tipped slightly below horizontal, the region insonified extends from directly below the transducer out to some 500 m or so abeam. The acoustic pulse length (typically 10 to 30 centimeters) is sufficiently short to permit the time resolution of echoes from small topographic irregularities and objects on or above the sea floor.

With a judicious selection of towed platform altitude above the bottom, the received echoes then form a line-by-line mosaic on a moving strip chart recorder or "waterfall" video display which resembles a topographic map. This

does not imply any valid indication of elevations or depths but is rather a plan view image of the bottom somewhat akin to an aerial photograph (with the realization that the viewing angle is oblique and not normal).

It is also possible to digitize the sonar return and perform a limited amount of real time processing on the digitized signals so that the display can more closely approxiamte a bottom map. For example, the along track distortion caused by variations in the speed of the platform may be compensated. Also, the timing across the display can be modified to display "true" horizontal range rather than the slant range of the actual acoustic pulse. (There is still a problem with objects in the water column.) Similarly, that portion of the display which depicts the travel time of the acoustic pulse to the direct bottom can be removed to eliminate this dead space. With such processing the sonar data is spatially corrected, but because of the oblique angle of view, large regions behind objects protruding above the bottom remain uninsonified and appear as shadows. Of course, the echo returns can also be stored for more sophisticated digital processing later.

The strength of the return signals depends not only on the limnology (features) and lithology (composition and structure) of the bottom but also on the range because of the water absorption and spatial spreading loss of the sonic beam. Range effects can be compensated with direct knowledge of beam shape and water properties, but the effects of limnology and lithology cannot be differentiated. A large return may come either from a very rough surface with a low impedance mismatch or from a smoother surface which has a larger impedance mismatch. If a quantitative indication of actual bottom returns is not desired (as it may not be in a search operation) then automated signal correction processing may be bypassed and manual gain controls adjusted for

maximum contrast or enhancement in any given region. An additional complication occurs with sloping bottoms whereby the strength of returns is larger from bottoms which slope up away from the platform and smaller from bottoms which slope down away from the platform.

Thus while side scan sonar records can be quite dramatic, and often quite informative, their interpretation requires skill and experience. Some success has been met in determining off-tract depth (Lowenstein, 1970) by utilization of an auxiliary receiving hydrophone whereby nulls may be determined at known angles and used to calculate height differences. However, for true topographic mapping, that is with elevation detail or bathymetry off-track, it would appear that multi-beam systems are required. These are covered in the following category.

4.1.5 Category E. MAPPING (MULTI-BEAM) SONAR

To date the only method of off-track bathymetric mapping in deep water involves multiple beam sonar. Two military systems currently in use are both superior to commercially available systems from the standpoint of swath coverage and number and resolution of receiving beams although the earlier, SASS (Sonar Array Subsystem), is now 20 years old. This system was developed by General Instruments Corporation, Harris Division. A newer Navy system is named BOTOSS and was developed by Sperry, Great Neck. Both these systems are hull-mounted and require dedicated ships, but towed versions are possible and indeed have been proposed. Obviously, deep-water bathymetry from a surface vessel imposes more severe requirements on the beamwidths permissable for desired bottom resolution than does the same bathymetry from a deep-towed platform, but in the deep tow case one is faced with the greater complexity of transmitting power down and information up a long tether.

The rationale of multi-beam bottom-mapping sonar is the division of the total athwartship coverage per sounding into a number of contiguous beams. This is achieved by forming one transmitted beam that is narrow in the fore-and-aft direction (2° to 5°) but broad athwartship (50° to 120°). A receiving array then utilizes contigious beams that are narrow athwartship (2° to 5°) but long in the fore-to-aft direction (15°-20°). The resultant effective beams are narrow in both directions)2° to 5°), yet provide adequate coverage across the track. The operative feature of course is that the sonar returns for each formed beam can be measured in time and so a slant range can be obtained for each beam. With direct knowledge of depth directly beneath the ship, these slant ranges are quite simply corrected to actual contour elevations for the off track distances calculated from the established beam pattern. It is noted that extra receiving beams may be employed to compensate for ship roll (up to 20°). The fore-aft extent of the receiving beams likewise compensates for ship pitch (up to 10°).

Deep water versions employ frequencies in the order of 15 kHz while shallow water implementations may utilize frequencies up to 40 kHz. Obviously, towed systems can operate with high frequencies. A proposal has been prepared for a 17 kHz deep water towed system. Another proposal involves the minor modification of an existing scan-within-a-pulse (SWAP) sonar operating at 200 kHz for shallow water bathymetry. This latter employs scanning athwartship rather than simultaneous formation of contiguous receiving beams.

With adequate knowledge of the water acoustic conditions, it is possible to correct the data obtained for each beam for raybending. Similarly the depth gates for each beam can be adjusted automatically, assuming adequate

vessel orientation data. The pulse repetition rate can likewise be automatically adjusted, and even more sophisticated processing/correction can be employed. The end result of these multi-beam sonars is a real contour chart of the bottom in almost real time.

4.1.6 Category F. SYNTHETIC APERATURE SONAR

As discussed earlier, along-track resolution of a Side Scan Sonar depends primarily on the transducer beam width which is a function of transducer size and operating frequency. A higher operating frequency permits a larger relative aperture (relative to the wavelength) and so leads to a smaller beam width and higher resolution. But the higher frequency also results in increased attenuation (as the square of the frequency), and the shorter wavelength permits the sound beam to "see" smaller in-water scattering objects (such as bubbles) which perhaps is not desirable.

For a given frequency there is a maximum reasonable limit to real aperature size and hence resolution. But as also mentioned earlier, the technique and concepts of synthetic aperture radar have been applied to sonar, resulting in an apparent aperture equal in size to the beam width at the range of interest. In this application, a small real aperture with a widely diverging beam is appropriate. As in synthetic aperture radar, in order to synthesize an aperture, it is necessary to combine coherently the sonar returns from many consecutive transmissions as the real aperture is moved along the aperture dimension to be achieved. This implies that the aperture track is quite accurately known. For example, if the synthesis is to be of a linear track, then any departures from this straight line course must be accurately compensated to within some small fraction (say 1/8) of a wavelength. This does not refer to terminal-point corrections but actual pulse-to-pulse corrections of track.

A second problem with synthetic aperture sonar relates to the characteristics of the medium itself. Specifically, if the coherence length of the sonar medium is not itself sufficiently large then it becomes a determining factor in the size limit of the aperture that can be synthesized. Here both moving scatterers and water turbulence, both active and "fossil" (the "signature" left behind after water motions cease), can doom the technique.

Although this discussion addresses active side-looking sonars, the synthetic aperture technique also finds application to passive (listening) arrays where the present good azimuthal resolution is achieved by the use of long towed receiving arrays with their concommitant speed limitation and maneuvering constraints.

It is worth noting that the basic problems with synthetic aperture sonar are traceable to the relatively slow (with respect to electromagnetic waves) propagation speed of sound. This means that the time required for synthesis of a desired array length is correspondingly increased since more time must be allowed for each echo return. These slow translations obviously worsen the effects of platform motion irregularities and medium propagation fluctuations. Any attempt to increase the rate of coverage leads either to a "thinned" synthetic array where the interelement spacings are so large that grating sidelobes appear, or to even slower platform speeds. The interelement spacing refers to the successive positions of the real array for each sound transmission. The grating lobes that appear for large unfilled regions are equal in magnitude to the main lobe and lead to azimuthal ambiguities; the first order lobes appear at $\lambda/2VT$ radians, where λ is acoustic wavelength, V is platform speed, and T is interpulse period (reciprocal of pulse repetition frequency). It is possible to remove the azimuthal ambiguities by increasing the real aperture length, but this decreases the azimuthal resolution. It is noted that

the synthetic aperture technique results in azimuthal resolution which is independent of both frequency and range. As mentioned, the maximum aperture length that can be synthesized is equal to the beamwidth of the real aperture at maximum range. This is equivalent to specifying the azimuthal resolution (independent of range) as equal to the length of the real aperture (for a single beam system). The only recourse for regaining the azimuthal resolution lost by increasing real array size is the employment of multiple beams. This can be accomplished either with multiple illuminating beams with a larger total length (it is immaterial how the insonification is produced, by one beam or several) or by filling the array with receive-only hydrophones. The resultant array pattern is then the product of the thin synthetic transmit array and the filled synthetic receive array. If the chosen solution is to fill the array with hydrophones, then it is necessary for the snythetic receive array pattern to have nulls at the locations of the synthetic transmit array grating lobes. This is accomplished by selecting the length of the real receive array as twice the distance traveled by the platform in an interpulse period. If, alternatively, the solution chosen is to employ multiple illuminating beams, then the number selected is determined directly by the resolution improvement desired. A recapitulation of all this above is given in the following paragraph, wherein the order of selection of parameters for a synthetic aperture sonar is displayed in a methodical manner.

The steps in the selection of parameters for a synthetic aperture sonar are designed to avoid ambiguity. The first step is the determination or selection of an unambiguous maximum range R. This fixes the pulse repetition frequency (prf) of the interpulse period T which is the reciprocal of prf as

$$R_u = \frac{CT}{2\gamma} = \frac{C}{2(prf)\gamma}, \ \gamma \geq 1$$

where C is the speed of sound in the medium (water). This relationship between unambiguous range and interpulse period eliminates range ambiguity. That is, the interpulse period T cannot be less than the time interval between transmission of a pulse and reception of a reflection from the maximum selected unambiguous range. Alternatively

$$R_u \leq \frac{CT}{2} .$$

The second selection step is designed to avoid azimuthal ambiguities. This is most easily approached from sampling theory which requires that the sampling rate, here the prf, must be at least twice the bandwidth. Since the latter is equal to V/D where V is platform speed and D is real aperture length, this restriction becomes

$$prf = \frac{1}{T} \geq \frac{2V}{D}$$

or

$$prf = \frac{2V}{KD} \ , \ k \geq 1$$

This latter relationship now establishes a minimum value for D (for a preselected V). The fact that D must be sufficiently large to avoid azimuthal ambiguity runs counter to the need for high resolution. The finest resolution obtainable for a single beam is

$$\delta_a = D/2.$$

(This is a factor of 2 improvement over real aperture sonar. The reason will not be further developed here but has its origin in the sequential sampling in

synthetic aperture sonar vice the simultaneous reception for a real aperture system). This resolution can then be improved simply by the use of multiple illuminating beams such that

$$\sigma_a = \frac{D}{2n}$$

where n is the number of such beams.

It should be noted that the above result could alternatively be considered as an increase in mapping rate for a given resolution rather than an increase in resolution for a given mapping rate. The mapping rate is given approximately by the product of platform speed V and maximum unambiguous range R_u since the latter is nearly equal to the horizontal swath. From the two equations for prf (or 1/T) we have

$$VR_u = \frac{CD}{4\gamma k}, \quad \gamma, k \geq 1$$

From this we note that if a given D is divided into n parts, this is equivalent to multiplying V by n. Another complementary means of achieving a greater mapping rate suggests itself from the above VR_u product. If R_u is divided into several sections, and each section is illuminated with a separate elevation beam each utilizing a distinctive frequency, then the interpulse period is correspondingly reduced by the decrease in each subswath of range. That is, the continguous elevation beams illuminate the entire swath but each beam need avoid ambiguity only for its own subswath.

Azimuthal resolution only has been covered in the preceeding and has been established as (1/2) the length of the real aperture for a single beam synthetic aperture sonar system, independent of either frequency or range. This

means that the operating frequency can be lowered to achieve longer ranges (assuming an adequate beam pattern) by capitalizing on the lower absorption loss. Resolution in range, however, is the reciprocal of the frequency bandwidth. For a single frequency sonar the pulse energy is directly proportional to the time duration of the pulse while the frequency bandwidth is inversely proportional to the time duration. The performance of, for example, sub-bottom pingers (covered in more detail later) is severly limited by the fact that the product of their pulse duration and bandwidth (equivalent to range times resolution) is always unity. For other than sub-bottom application, including synthetic aperture sonar, it is possible to employ long time-bandwidth product signals, such as coded pulses or linear FM chirp, not only to achieve high signal energies but also larger bandwidths (which correspond to increased range resolution). As an example which distinguishes between operating frequency and bandwidth, a linear FM chirp sweeping from 12 to 17 kHz in a period of 5 milliseconds has a mean frequency of 15 kHz and a bandwidth of 5 kHz. This latter provides a resolution in arrival time estimation (assuming a matched filter) of 200 microseconds, corresponding to a range resolution of 15 cm.

It should be noted that in synthetic aperture sonar the signals in storage can be selected by range and, if desired, processed differently - one example would be focusing. Thus, if the platform position, altitude, rate, and rate rates in relation to the ideal straight line track are known to, say $\lambda/8$ (corresponding to less than 1 cm at 15 kHz over distances of tens of meters), then resolutions of the order of centimeters at ranges of the order of several hundred meters with arrays of a few meters length can be achieved by using multiple transmitting beams and focusing the receiving array at specific range-azimuth cells by computer generated delays between the individual elements.

The foregoing explanation of synthetic aperture sonar is based on communication theory wherein range resolution is considered via the filtering of doppler frequencies. The low tow speeds required for sonar imply a small doppler or szimuthal bandwidth for the system and therefore seem to offer little potential for subsequent azimuthal compression of the data to achieve extremely high angular resolution. However, consideration of synthetic apertures from the holographic viewpoint removes the need for doppler and leads to a different design philosophy. Considered in this manner a synthetic aperture sonar record is a one-dimensional zone "plate" which reconstructs an image in two dimensions (an ordinary optical hologram is a two-dimensional zone plate which reconstructs in three dimensions). It is worth noting that there is no requirement for focusing in optical holography (acoustical holography is covered briefly in Category H). There does not appear to be any developmental work in the civilian sphere concerning synthetic aperture sonar. Certainly there is no commercially available system, although tests have been run by several organizations. At least one classified military system is in existence.

4.1.7 Category G. PARAMETRIC SONAR

Ordinary Side Scan Sonar (Cat. D) involves a trade-off between area coverage rate and the range-resolution product. That is, azimuthal resolution is inversely proportional to range due to beam spreading, and the pulse repetition rate is limited by range ambiguities which require slow tow speeds to compensate for the slow acoustic propagation speed. Synthetic Aperture Sonar (Cat. F.) develops an effective aperture equal to the width of the real beam at the range of the target for excellent azimuthal resolution independent of either frequency or range so that a lower frequency can be used to achieve

longer ranges. Synthetic Aperture Sonar also offers range resolution equal to the reciprocal ofthe frequency bandwidth so that long time-bandwidth product signals such as linear FM chirp permit high signal energies as well as good range resolution. But as stated previously, the necessity for coherent addition of the many returns over the length of the synthetic aperture (maximally equal to the beamwidth of the real aperture at maximum range) means that data on the motions of the tow vehicle and fluctuations in the propagation characteristics of the medium must be recorded in real time and nearly continuously *in real time.* Parametric Sonar offers an alternative means of achieving good resolution at low frequency for increased range and/or bottom penetration.

Parametric Sonar utilizes the non-linear effects of finite amplitude sound. Acoustics per se is the stude of pressure waves of infinitesimal amplitude where the speed of sound is assumed to be equal for both positive pressures and negative pressures. For finite amplitudes with high positive and negative pressures, however, the positive half cycles of a sine wave travel faster than the negative half cycles. The result is the eventual creation of a saw tooth wave at some distance from the source. Such a wave contains harmonics whose intensities increase with the source intensity. If two such beans of slightly different frequency overlap the interaction between these non-linear components results in a beam whose frequency is the difference between the two primaries involved. The actual mixing region has been likened to a semi-infinite end fire array with exponential taper. The end result is a low frequency sound beam that is very narrow and has no side lobes. Parametric sources exploiting this effect are commercially available.

Parametric sources utilize fairly high primary frequencies so their physical aperture can be relatively small. The low frequency beams they produce are in the order of a few hundred Hertz with beamwidths of only one degree or

so. As mentioned the beams have no side lobes. The difference frequency can be varied over a wide range with little effect on beam widths. However, since the parametric beam is the result of the non-linear interaction of primary beams, the efficiency is quite low and decreases with the ratio of primary frequency to difference frequency. Many applications of parametric source/ receiver systems can be envisioned. The system itself has been described as an acoustic laser.

4.1.8 Category H. ACOUSTIC IMAGING/HOLOGRAPHY

As discussed in Category J, Snythetic A perture Sonar is a technology which can be considered as two-dimensional holography utilizing one-dimensional zone plates. The acoustic holography discussed here is the three-dimensional acoustical equivalent of Optical Holography.

It is a fact that coherent transmitters of acoustic waves were available long before lasers, their optical counterpart. The need in acoustics, though, is for a substitute for the area detector used in optical holography. For the latter, of course, this is a photographic plate or film. A candidate for the acoustic counterpart might be a microphone or receiver with a diameter comparable to or less than the fringe spacing in the interference pattern generated dby the reference and input beams in the plan of the hologram. It is worth noting that whereas film responds to optical intensity, or the amplitude squared, the microphone responds to the amplitude only of the acoustical field. Therefore the acoustical reference beam required for strict optical anology can be replaced by an electronic reference signal. Indeed it can be stated that acoustical researchers had "discovered" acoustical holography long before they realized it.

Liquid-surface acoustical holography closely parallels optical holography by replacing the film with a liquid surface whose deformation by acoustic radiation pressure is read out optically. This system has been used in the laboratory but has obvious drawbacks in the field. It is however, an instantaneous system. The single acoustic microphone noted above would have to be used as a scanner to build up the hologram point-by-point. Obviously a line array or even an areal mosaic could be employed with suitable processing to yield a real-time image.

A very simple method of recording the acoustical hologram would involve a small lamp tracking the microphone or possibly, lamps properly connected to an array. If the brightness of the lamps were caused to vary in accordance with the phase and amplitude of the received signal (mixed with the reference) and this brightness were recorded on photographic film in a one-to-one spatial relationship then the resultant developed transparency would serve as a hologram. Actually, source, receiver, or both may be scanned. An optical image of the object as viewed by sound can then be produced by illuminating the hologram with coherent light. However, because the angles of diffraction are small (re optics) and the hologram-to-image distances are great (except for focused image holograms) an auxiliary lens is usually used to bring the undiffracted light, and hence the true and conjugate images, closer to the hologram for simpler viewing.

One major problem in optical reconstruction for viewing is the large ratio of optical to acoustic wavelengths. This causes severe distortion, whereby the image is greatly stretched in the radial direction with respect to the lateral directions. No apparent cure for this has been found to date. There is not much activity in acoustic holography at the present time.

4.1.9 Category I. ACOUSTIC POSITIONING/NAVIGATION

This discussion begins with acoustic navigation by which is usually meant doppler sonar or doppler speed logs. Such systems reflect the desirability of true speed measurement over the bottom for accurate navigation, mooring or dock approach, or anchoring. The operating principle is that a received echo will experience a frequency shift relative to the transmitted frequency in a manner directly proportional to the relative velocity between the source and the echo producing object. If the motion results in a closing range the frequency will increase, and conversely a decreasing frequency indicates an opening range. In those cases where the bottom is not acoustically visible a range gated reverberation volume several meters away from hull flow disturbances is used for the doppler indicaton. Effects of pitch, roll, and bottom slope are partially compensated for by utilizing four transducers and comparing the fore and aft measurements as well as the port and starboard ones. Characteristics of the ocean bottom have a minimum effect on the accuracy of the system. Typical bottom ranges extend to 600 m and operating frequencies are in the few hundreds of kilohertz. Of course, the doppler method requires narrow beams and in the example above, four of them. The doppler method is not independent of the speed of sound in the medium and is not completely free of the effects of bottom scattering.

A correlation technique not based on doppler shift is available whereby a single wide beam is transmitted vertically downward and several hull-mounted hydrophones in a nominally horizontal plane array simultaneously receive echoes from each of several transmissions. The correlation is maximized for pulses separated by a known time interval, for a calculated separation vector representing the horizontal velocity component, and a calculated time delay representing the vertical velocity component. It can be shown that bottom

characteristic dependence is completely eliminated and local sound speed affects only the small vertical component of vessel travel. The correlation technique employs a wide beam with a wide bandwidth from a small aperture vice the narrow beams with narrow bandwidths and large transmit apertures required for doppler navigation.

A sub-category of this technology is represented by the relatively simple pingers and beacons which are used for marking and location. Such systems generally yield direction only and lack range capability.

A major portion of this category is devoted to acoustic positioning. The technique here is to determine the position of a vessel, towed body, or submersible in relation either to a single transponder or pinger or to a fixed grid of transponders mounted at some distance above but near the sea floor. Those employing a single bottom source are referred to as short base line systems and use, aboard ship, either a single three-element hydrophone array or three hydrophones spaced in a triangle with sides of the order of 10 to 20 meters. The single split receiving hydrophone system is sometimes referred to as ultra-short baseline.

Ultra-short baseline operation with a free running bottom pinger is perhaps the simplest positioning determining method. Systems operating in this manner can measure phase only and operate by determining the phase difference noted on each of three elements of a receiving hydrophone whose orientation with respect to the X, Y, Z axes of the vessel is known. This informtion, together with knowledge of the depth or vertical separation between the pinger and the hyudrophone is sufficient to determine the vessel's apparent position with respect to the pinger. Pitch and roll compensation may be employed by use of a vertical reference sensor. Obviously the above ultra-short baseline system with a free-running bottom pinger is most useful only for small horizontal offsets and for operation in waters of known depth.

Bottom Transponder-mode operation with the same shipboard split hydrophone is more accurate than is the free-running pinger system. It is more useful for horizontal separations from one to two times the vertical separation and does not require independent knowledge of water depth. Operation consists of the vessel hydrophones interrogating one or more near-bottom transponders and determining not only phase (in the same manner as from a pinger) but also slant range from the two-way acoustic pulse propagation time. Pitch and roll compensation may be employed as before.

For deep-towed vehicles or tethered submersibles a responder mounted on the undersea platform van be electrically interrogated through the tow cable or tether to yield positional data with respect to both the surface vessel and a near-bottom transponder.

Long-baseline techniques offer increased range capability and improved positional accuracy especially at greater depths. In this technique a grid comprised of from 2 up to as many as 16 near-bottom mounted transponders is used in conjunction with a single shipboard mounted hydrophone. This multi-transponder long-baseline mode of operation begins with a calibration of the relative position of each transponder in the grid. This is achieved by several preliminary "runs" through the grid, interrogating each transponder and allowing all transponders to "talk to each other." After the initial calibration, interrogation and vessel position "fix" is made in the same way as for the short-baseline mode but the accuracy is obviously increased. Of course, the position of a towed fish or tethered submersible can again be determined by a responder mounted on the submerged platform. An untethered submersible can also be precisely located by interrogation of a transponder carried by it. Long baseline systems can operate with transponder separations of several kilometers in deep water. Interrogate and reply frequencies are of the order

of 10 kHz. Although it appears feasible to correct for sound ray refraction and bending, this is not done in commercially available equipment. At least one company suggests that ray tracing be used to optimize transducer depth for maximum range. Accuracies claimed are as small as 2 meters with slant ranges up to 5 kilometers.

4.1.10 Category J. ACOUSTIC COMMUNICATION

As with most underwater acoustic technologies, communication by this means is again conceptually simple. The workhorses here are the US Navy's UQC operating at 8.0875 kHz and the WQC at 10.3 kHz. Ranges may vary from 400 to 4000 meters depending on sea state. The primary limitation to extended range is the same factor affecting all underwater acoustics, specifically the propagation characteristics of the medium. For communication the most serious problem is multipath propagation. This may be attacked by frequency selection or swept-carrier transmission. Apart from sending voice or code, acoustic communication links have also been used successfully for slow scan television transmission over an essentially vertical path. Horizontal path slow-scan video transmission has been tested in a 600 ft. deep lake where use was made of a parametric sonar with a 10 kHz difference frequency and a 2 degree beamwidth.

4.1.11 Category K. ACOUSTIC BOTTOM PROFILING

The operational characteristics for a bottom profiler are much like those of an Obstacle Avoidance Sonar. The requirement is obviously for an active system. Here detection is of a small region of a continuous reflector rather than an isolated object in the water column so the use of a wide beam projector and a narrow beam hydrophone is ruled out. Both should have small angular coverage although limited divergence of the outgoing beam is more important.

To avoid sub-bottom reflections the output power should be minimal and the operating frequency high enough to reduce bottom penetration. Fortunately this last choice operates in harmony with the desire for a narrow beam. Depths approaching 10,000 meters can be determined to an accuracy of a few meters. Hydrophone/projector stabilization or compensation for vessel roll and pitch is an obvious requirement. Since the acoustic beam is vertically oriented, no correction for ray bending is required, but sound speed correction may be utilized.

4.1.12 Category L. ACOUSTIC SUB-BOTTOM PROFILING

Unlike the previous category where a higher frequency was preferred to minimize bottom penetration, here obviously a lower frequency is required to enhance such penetration for sub-bottom profiling. It should be noted that this category is restricted to acoustic reflection methods; seismic refraction is not being considered here.

Again, the concept is simple; an acoustic pulse is directed at the bottom and reflections from various layers of differing material are observed upon their return. The source must have two characteristics besides a low frequency which is generally of an order of 5 kHz. The pulse length is of prime importance because layers or objects can only be resolved if they exceed a separation equal to the product of the transmitted pulse length and the speed of sound in the material. A second requirement is for a clean pulse shape without ringing or other back responses which confuse the echo return. The acoustic beam should be as directional as possible without side lobes which can also mask bottom details. Here, or course, a conflict arises between the desirability of a norrow beam and the low frequency required for adequate bottom penetration which also requires maximum power. It is no surprise then that there are two basic types of sub-bottom profiling (reflection) systems.

One utilizes a common, usually towed, projector/hydrophone emitting energy in a cone with an angle of the order of 50°. The other utilizes separate acoustic sources and receivers. In this latter method the source is either a bubble pulser, an electromagnetic boomer, or a spark discharge (explosives are not considered here). These sources obviously yield broad spectrum, wide angle pulses that nonetheless can be of minimal duration (down to 0.2ms). The more powerful sources have longer pulses so that the typical resolution varies from 15 cm to 5 meters in an inverse trade-off with bottom penetrations which typically range from 30 to 1200 meters. It should be noted that although narrow beams yield cleaner records with sharper delineation of small areal irregularities or changes, the wide beams yield records approaching the zone plate patterns of acoustic holography, viz., a nearly point reflector displays a hyperbolic record return as the system traverses the object. This is actually preferred by some investigators.

The use of a separate hydrophone permits optimization of signal to noise ratio in a manner not achievable with a combined projector/hydrophone. As a simple example the hydrophone can be towed at a distance from the ship to remove it from the vessel's own noise. This can be at an even greater distance than the source if the latter is also being towed. The hydrophone can consist of separated active elements in a towed array so that noise from the ship arrives along the axis of the array. The noise is therefore phase shifted by the time lag and so is not coherently summed as is the bottom echo return. In addition, the tow noise on each element has less contribution in the summation of all recorded signals. Finally, even the omnidirectional ambient noise is reduced in impact by the directional character of the array which discriminates against non-normal arrivals.

It must be noted that all layer thicknesses are indicated only as a function of time and can only be considered approximate without accurate knowledge of the speed of sound in the layer. Further, the travel time indication is only valid for a collimated beam. The diverging beam not only indicates an average over an area increasing with depth but also complicates the possible analysis of multiple reflections within layers. Again the use of time-variable gain or other attempts to equalize the record can introduce more complications in the analysis. Because of the complex nature of the record very little in the way of automatic correction or processing is done in the technology of Sub-Bottom Profiling.

4.1.13 Category M. ACOUSTIC ENVIRONMENTAL

As discussed in the introduction, this category consists of acoustic current or flow meters and in-situ sound speed measuring devices. Ultrasonic current meters utilize the travel time difference principle. Ultrasonic waves in the low megahertz range are sent in opposite directions between two combined transmitter/receiver transducers. The acoustic path may be folded by means of a mirror reflector. The basic measurement involved is either the travel time difference noted above between the up and down stream pulses or the difference in phase between these same pulses. The measuring range can extend from 0 to $\pm$ 250 cm/sec or greater with claimed accuracies of 3 to 5% and resolutions of 0.1 cm/sec. It must be noted that the acoustic path length must be known to the desired accuracy as must also be the speed of sound in the water. For the phase difference technique the acoustic frequency must also be known, but this method permits heterodyning to a lower frequency which still contains the same phase information as the original megahertz acoustic signal. The resultant voltage, proportional to current speed, can also be

combined with a magnetic compass output to yield components proportional to North-South and East-West flows with claimed directional accuracies to ± 5°. The combined resolver outputs can also be time averaged. For the travel time difference method the possibility exists for a harmonic analysis of all existing wave motion components in the fluid.

These ultrasonic flowmeters obviously measure only the components of current flow in the direction of propagation. For a horizontal orientation any vertical components do not affect the measurement. If components of flow in other directions are desired, then another orientation of transducers must be used. Three sets are required for a complete flow profile.

Another system for measurement of vertical current profile (horizontal speeds and directions) in the upper ocean is based on the 4-beam doppler principle previously discussed for navigation. This system is good to depths of 500 feet or so and ship speeds of 15 knots. The time-of-flight difference and phase difference techniques described above obviously sense flow and/or sensor motion through the water mass. Unfortunately the four-beam doppler system also yields a frequency shift proportional to the velocity of the vessel relative to the water mass scatterers along the beam However, the current profile is obtained in bins (32 for one example) related to the various depths of the beams and converted to a fore/aft and port/starboard depth profile. Obviously the ship velocity re the ground must be subtracted from the ship-to-scatter velocity in order to obtain the current profiles. Ground referenced velocity may be obtained from doppler sonar if the bottom is within range. Otherwise some other ship speed data source must be utilized.

The second instrument type under this category measures the speed of sound in-situ and is sometimes referred to as a sound velocimeter. Such an instrument usually measures a quantity which is related to the speed of sound,

rather than the velocity itself. Some early instruments relied on the measurement of the resonance frequency of a defined volume of liquid in a container of specified geometric form. These were never developed into commercial instruments because their differential nature involved rather tedious and somewhat uncertain calculations. Moreover, the effect of wall cleanliness (or fouling) is large, as are possible changes in shape or symmetry of the container.

Non-expendable commercial acoustic velocimeters are now all of the type originally developed at the National Bureau of Standards. In these "sing-around" velocimeters two transducers and a reflector are mounted in the manner used for acoustic flowmeters, but propagation occurs in one direction only. Moreover, to increase sensitivity, travel time is not measured directly but rather the received pulse is allowed to trigger another transmitted pulse so that a self-repetion rate (sing-around frequency) is created. The interval between pulses is the reciprocal of the sing-around frequency and is the sum of the travel time in water and an effective electronic time delay. Thus

$$\frac{1}{f} = \frac{A(1 + \alpha T + \beta T^2)}{C} + B$$

where f is in hertz, C in m/sec, and T in degrees centigrade. Here also A is the effective path length in meters at 0°C, B is the effective electronic time delay, and α and β are the thermal expansion coefficients of water. If $\beta = 0$ then

$$C = \frac{A(1 + \alpha T)}{(\frac{1}{f}) - B}$$

and if $\alpha = 0$

$$C = \frac{A}{\left(\frac{1}{f}\right) - B}$$

If $B \approx 0$ (usually $\sim 0.2\,\mu sec$)

then $C \approx kf\,(1 + \alpha T)$.

The problems inherent in this technique are exemplified by use of the adjective "effective" in denoting the path length and electronic time delay. These can only be obtained to the required accuracy by calibration with accepted sound speed tables. With proper calibration data can be obtained with accuracies of 55 ppm.

This technique for determining sound speed in-situ has been developed into a sufficiently low cost expendable instrument. Using a wire link to the surface vessel an accurate path length sing-around circuit mounted on a carefully calibrated afterbody is launched into the water. The rate of fall is used to determine depth to $\pm$ 2% or 5 meters down to 850m. The sing-around frequency of 27 to 30 kHz is counted down and a 210 to 233 Hz signal is sent up the wire link to indicate sound speed. Laboratory measurements (as a function of temperature only) have been made with an accuracy of 0.1 m/s while the claimed overall accuracy is $\pm$ 0.25 m/s.

4.2 OPTICS

Optics plays a major role in underwater sensing systems, second only to acoustics, but with much greater resolution for the smaller ranges over which it is effective. Rather than being a propagating pressure disturbance of the medium as is sound, light involves the propagation of photons, which undergo a much greater absorption and scattering loss. Even at the transmission window

located about 480 nm in deep ocean water, the scattering loss for a beam of light is over 1000 times that for clean air. Especially for pulsed applications the logical choice for an underwater optical illumination source is a blue-green laser. Optical detectors range from film (sometimes enhanced by coupling to intensifiers), through photodiodes and photomultiplier tubes, to TV sensors including solid state arrays. Rather than concentrate on the specific details of source and detector and the many optical properties of the medium at this point, specific details, including the pertinent ocean parameters, are discussed in the specific technology for which they first assume importance.

4.2.1 Category N. OPTICAL DETECTION/LIDAR

This category is composed of optical detection systems where pulsed or gated lasers operating in the blue-green wavelengths are the normal source. This section is also restricted to detection of the bottom for shallow water bathymetry from aircraft and to detection of shallow submerged obstacles from a high speed hydrofoil. It should be noted that the angle of incidence with the surface varies from near normal for the former to near grazing for the latter. For a ranging application like bathymetry a resolution of a few tenths of a meter requires nominal pulse lengths of a few nanoseconds, although signal processing, especially correlation, can permit the use of longer pulses having correspondingly greater energy.

Such narrow pulse requirements restrict the choice of laser. The tuneable flashlamp pumped dye laser which will be seen to be so effective in gated bottom imaging has too long a p ulse for ranging measurements. Although cavity dumping appears to be a logical means of shortening the pulse length without sacrificing energy, there has been no convincing demonstration of this

technique to date. Thus candidates appear to be restricted to dye lasers pumped by ruby, glass, or N_2 sources, or doubled Nd-YAG, at least until such time as cavity dumping techniques become feasible. It does not appear at this time that Cu vapor lasers are viable candidates for either detection or imaging, and excimer lasers require much improvement if they are ever to be useful underwater. Vortex-stabilized flashlamps are under development, but because of the hardware necessary for sustained closed-cycle gas flow, they are large, heavy, and complicated. Frequency-doubled Nd:YAG lasers have an output of 150 milli-Joules or so, with pulse widths of the order of 15 ns, at pulse repetition rates of 10 Hertz. A tradeoff can be performed so that 5 mJ pulses can be obtained at a 400 Hz rate. The overall efficiency is only 0.1-0.2%. The wavelength of operation of a Nd:YAG laser is 532 nm vice the 480 nm at which maximum transmission occurs in deep ocean water. By comparison, metallic copper vapor and copper halide lasers operate at 511 nm. A dye laser, of course, no matter what its excitation, can be tuned to almost any output wavelength. In particular, LD490 dye in methanol has been found to have a half-life under flashlamp excitation of some 10,000 one-Joule output pulses per one liter of dye solution with an overall efficiency of better than 1%.

The detector used for bathymetric lidar is most generally a photomultiplier tube which may or may not be operated with a filter. For example, in an attempt to minimize daylight background, consideration has been given to operating a laser at one of the Fraunhoffer absorption lines, e.g., the H_β line centered at 486.1 nm. For a 0.1 nm filter, the signal-to-noise ratio improvement is 2dB out-of-band and 7.5 db in-band.

Calculations have been made for 100 m depths, but bathymetric results have not been obtained over 20 m to date. A two-color LIDAR has been shown

capable of detecting submerged objects to depths of 5 meters at angles of incidence greater than 85 degrees, but it should be noted that operation at 532 and 1064 nm was found to offer no advantage in the detection of such sub-surface targets. It is anticipated that this dual channel technique may be able to discriminate against partially submerged objects, white water, and other surface phenomena.

4.2.2 Category O. OPTICAL IMAGING-AREAL

This category includes all non-scanning (staring) optical imaging with the exception of the range gated imaging under Category P. Scanning of a vidicon target for readout is not precluded here, but scanning of the object field is discussed in Category Q. Both photographic film and TV cameras are included in this "instantaneous" two-dimensional imaging.

If the imaging is restricted to shallow depths and daylight hours then many film and TV cameras either modified or originally designed for underwater use are capable of excellent imaging. For relatively short ranges in clear water full color imaging is possible. But because of the spectral attenuation characteristics of water (minimum circa 480 nm) only black and white (or shades of blue) imagery is feasible at ranges beyond 1/2 m or so. This is especially true if artificial lighting is required, even if the illumination is by white light. But it is indisputedly true that color imaging is extremely useful, even at this short range, to document the onset of corrosion (usually shown by brightly colored compounds). Color imaging can also reveal fatigue or crystalline failure cracking by the brilliant prismatic (diamond like) reflections.

For maximum range and/or areal coverage per image it is obviously preferable to use a light source with wavelengths located at the optical window of

480 nm. Nevertheless successful photographs have been made with Xenon strobe arcs and shutterless cameras in deep water.and quartz-iodine or xenon arc lamps have been used for movies, TV, and shutter photography. Such bright sources lead to a direct confrontation with the nemesis of underwater optical imaging, because the primary limit to increased viewing range is backscatter, which acts to eventually mask the object in a glow field or glare. While it is true that computer contrast stretching or enhancement can overcome the pedestal of backscatter to a limit, it is likewise true that if the backscatter is so severe as to drive the detector into saturation, then there is no means of recovering the image. The connection to backscatter of these white-light sources is that for reasonable ranges of 5 m or more the non-blue-green components of light add to the backscatter while not contributing to the illumination. Even a Nd:YAG laser falls to 1/e in half the distance a tuned dye laser does.

The standard technique for minimizing backscatter is by geometric placement of source and detector. In the same manner by which the use of high headlight beams while driving an automobile in fog effectively blinds the driver while the low beams permit better vision, so too does lateral separation of source and detector decrease backscatter by diminishing the volume of illuminated water through which the detector must look to image the object. Obviously, in conjunction with this lateral separation, the use of beams with no greater divergence than is required to illuminate the object also decreases the amount of unnecessarily illuminated water. Conventional optical search systems are generally restricted to ranges of 5 m or so.

Two variations of the above conventional backscatter reduction technique have been employed. One carries the beam narrowing concept to its ultimate

and employs a very narrow illumination beam and a narrow field of view detector. In order to obtain areal coverage in this case scanning is required. This dual-scan concept is described under Category Q. A variation of this is a fan-scan system not unlike side-looking sonar, which is also described under Category Q. The second variation of the conventional backscatter reduction technique is to position the light well below the camers. This obviously delivers more light to the object and minimizes true volume of light-filled water from which the backscatter originates. Of course, the illuminated field is correspondingly decreased, and the source assembly is imaged as well.

An unconventional variation of this separation of source and detector to reduce backscatter is the NRL developed LIBEC (Light Behind the Camera) system. The original rationale was based on the observation that the best underwater photographs had been taken in shallow water where the source of illumination, the sun, was far above the object and indeed illuminated the entire optical imaging path. Computer runs did indeed indicate an improvement in signal to noise ratio or contrast when the source was displaced laterally by 1 m and vertically up to 10 m. In practice this places the camera in a more vulverable position since it is suspended below the vehicle carrying the source. Here the source is not imaged although a shadow of the camera may appear in the field. Of course, light is "wasted" in this configuration, but the large gain in contrast permits wide angle ranges up to 20 m for the most effective bottom photographic coverage. This was successfully exploited during Project FAMOUS (French American Mid Ocean Underwater Survey). Somewhat difficult to grasp conceptually, a bit of insight into the technique can be obtained as follows. Consider a camera and source with a nominal lateral displacement of, say, one meter. Then, instead of visualizing a comparison between this geometry and one in which the light is moved vertically behind the

camera, consider the camera moved below the source (maintaining the lateral separation). A plausibility argument can be made that the illumination on the target (or bottom) is the same in both cases, that the image light received by the camera has increased (because of the reduced object to detector range), and the backscatter received by the camera has actually decreased because the illuminated volume has decreased. With an increased signal and decreased backscatter the recorded image is obviously greatly improved.

This same LIBEC technique was further improved by the use of diode intensifiers (miltichannel plates) in a 70 mm format camera. Their use with two 300 Joule sources, yielded photographs subjectively equal to the non-intensified ones obtained with one 8250 Joule source.

Low light level TV has been used successfully under water. No TV system to date is the equal of a good film record, but excellent close-up color images have been obtained recently with an RCA developed CCD color TV camera.

4.2.3 Category P. OPTICAL IMAGING - RANGE GATING

Although range gating is another solution to the backscatter problem, it has not been successfully demonstrated as yet at sea. Possibly the development furthest along is the NRL SEGAIP (Self Gated In-Water Photography) system which has been successfully tested in air at a range of 30 meters.

The principle is again fairly simple. A light pulse of sufficiently short duration is sent out, and the detector is opened only for a period equal to the duration of the emitted pulse, at a time which permits only the return from a certain range of interest to be received. Since the only backscatter received by the detector is that arriving during the receiver gate-on time and that backscatter originates at the range of interest (where the backscatter

return is diminished) the contrast in the image should be improved dramatically over a non-gated system. Obviously a fast rise and fall-time optical pulse is required as well as a fast turn-on and turn-off receiver. If the receiver gate is adjusted to some time other than the round trip travel time then the object will not be seen.

A modification of this general range-gate system can be employed, especially if the interest is photographic or TV coverage of the bottom. In this case there obviously is a time after transmission of a light pulse beyond which no light travels away from the detector and hence produces no backscatter. There is also a time beyond which no image return occurs. The point to be recognized here is that the light pulse need have only a sharp cutoff and the detector need have only a sharp turn-on. A useful elaboration of such a system would involve automatic photomultiplier tube detection of the image light return and subsequent gating-on of the detector. This would remove the necessity for manually changing the delay time between the triggering of the light pulse and the triggering of the detector. In this was the timing would always be correct for an object at any reasonable range, whether it be a changing bottom or something in mid-water. It should be noted that if the timing delay were adjusted for bottom return only, a mid-water object would be noted only as a "hole" in the photograph, i.e., an apparent shadow on the bottom. Of course, with the self-gated feature described above the object could be imaged, with only minor complications.

For a quasi-range-gate application with self-gating as just described, it is no longer necessary to employ a very short pulse to isolate an object in space, if the essential nature of the task is bottom or near-bottom imagery. Indeed a light pulse can be employed that effectively fills (just once) the

entire range to the bottom. This not only simplifies the gating but also permits the required energy to be sent out in a light pulse with minimum peak power. This obviously decreases the stress requirements imposed on the optical elements of the source, and minimizes the risk of damage by the laser beam.

The implementation of the above concept at NRL has been given the name SEGAIP. It consists of a one Joule output flashlamp-pumped dye laser whose gated pulse can have both rise and fall-time of the order of 5 to 20 ns. A photomultiplier tube is used as the image-return sensor. The detector is a 3-stage intensified, gated film camera of 35 mm format equipped with a 90° water lens. The intensifier can be turned fully on in about 3 ns, remains at full gain and in focus for the duration of the image return, and turns off slowly over a period of about 1 μs (during which there is no input at all). The intensifier gain is 10,000 watts out (from the P20 phosphor) for each watt of 480 nm light in. In the clearest ocean water calculations indicate a possible range of 100 m with a viewing angle of 64° (reduced from the 90° lens because the intensifier is only 20 mm in diameter vice the 35 mm film). At a 10 knot towing speed pictures taken at 15 sec intervals would still produce over 50% overlap for the construction of a good mosaic (actually yielding several views of each object). The bottom areal rate of coverage translates to almost 10 km^2/hr for SEGAIP vice the 0.1 km^2/hr for LIBEC and the 0.01 km^2/hr for more conventional systems. It should be noted that the SEGAIP estimated coverage compares favorably with side scan sonar with the plus of much greater resolution and a much more vertical view of the bottom.

The near-elimination of backscatter and the increased optical range offered by SEGAIP require that the fundamental resolution limit to in-water viewing be considered. To reiterate, the primary limit is due to backscatter

from particles in the water. These particles amount to only 10 to 20 parts per billion by weight with a number density (in the 1 to 100 μm range) of only 200 to 2000 per ml. Scattering from such particles comparable to or larger than the wavelength of light is describable by Mie scattering. Although this is predominantly in the forward direction the comparable small backscatter is sufficient to cause the overall glow or masking effect that constitutes the primary limit. The ultimate limit to viewing in water is the photon limit-essentially a power limitation due to losses. Besides the spreading loss suffered by light, akin to other forms of wave propagation, an absorption loss coefficient some 1000 times greater than that of so-called clear air is experienced by the light beam. The relatively few particles account for about half of this loss. Besides the primary backscatter limit and the ultimate photon loss limit, there is a fundamental resolution limit which is also primarily the result of particles. In this case forward scattering from the particles creates blurring of the image. This degradation of resolution is expressed as a function of spatial frequency (in line pairs/mm or, even better, cycles/radian). The best measure of this is the image-to-object contrast degradation which is called the modulation transfer function or MTF. This is normalized for a given range (in air) at zero spatial frequency. Particle forward scattering results in the MTF leveling off or plateauing at some spatial frequency at a value equal to exp $(-\alpha R)$ where α is the beam attenuation or total loss coefficient and R is the range. Turbicles (patches of water characterized by a relatively uniform refractive index fluctuation that differs slightly from the surrounding medium) also degrade resolution, affecting even higher spatial frequencies than do particles. That is, turbicles cause even smaller forward scattering angles than do particles. This turbicle forward scattering results in a roll-off of MTF with spatial frequency beyond the particle scattering

plateau. This roll-off, modified of course by the transfer function of the optical system, then determines an absolute upper limit for the spatial frequencies that can contribute to the image at the given range. This is the fundamental resolution limit to optical viewing. For a single picture, no increase in illumination power, detector sensitivity, or amount of computer processing can restore the spatial frequencies beyond that value at which the MTF roll-off falls below noise, much less to zero.

4.2.4 Category Q. OPTICAL IMAGING - SCANNING

As noted previously, trhe second non-conventional method of reducing backscatter is the technique of carrying the beam-narrowing to its limit while also using lateral separation of source and receiver. This dual-scan concept probably achieved its maximum realization in ARPA's Project Deep Look which culminated in the Ball Brothers LOOK SEA system now stored at NUSC. The results obtained by this submarine-mounted system were approximately those achieved earlier by the Tetra Tech Fan Beam Volume Scan System. This latter employed a 20 . sec 4 Joule (input) pulsed flashtube with a scanning rate of 200°/second. Both the light source beamwidth and camera viewing angle were 2° X 50°. The lamp to camera spacing was 4 feet on a diver-held support and the stated range was 5 attenuation lengths. A variation of this fan scan technique has been proposed by NUSC. Named FANSCAN it was to employ a Xenon short-arc continuous illuminator, producing a fan-shaped beam 1° X 90°. The illuminated strip was to be scanned by photo-electric sensors coupled to a video-tape real-time display, but a framing camera version of the system was also envisioned. This optical analog of side-looking sonar obviously would employ no moving parts. It was expected to have an angular resolution of 2 mr and an improvement of a factor of 2 in range over presently available devices.

The estimated range was 3.5 attenuation lengths. In common with all scanning methods (vice snapshot or staring systems) FANSCAN builds up the image one line at a time and so requires good aiming and track direction and speed stability to avoid the distortions otherwise inherent in scanning. The platform stability (or corrections thereof) is not as stringent as for synthetic aperture sonar but is similar to side looking sonar requirements.

A final variation of optical imaging by scanning is the ROMS (Real-Time Optical Mapping System) developed as a demonstration model by NOSC. This employed a 1 mr, 5 watt laser beam as an illuminator and a photomultiplier tube as a receiver. These are coupled by a mechanical, rotating scanning mirror system, and this narrow-angle optical synchronous coupling was expected to result in a "maximum" reduction of backscatter. The use of high power illumination was to maximize viewing range. It is noted that this one dimensional line scanning also relies on vehicle motion to provide the second dimension required for area coverage. The system depth of field could be considered to be the vertical dimension of the intersection of the projected light beam with the receiver field of view. It was assumed that the resolution was determined by the illuminator beam divergence, and the anticipated range was to be be tween 4 to 8 attenuation lengths.

It should be noted that resolution claims for both SEGAIP and ROMS did not invoke modulation transfer function calculations, and the viewing ranges are hypothetical with no concomitant resolution statements.

4.2.5 Category R. OPTICAL COMMUNICATION

As stated in the Introduction, the only applications of this technology appear to be classified and involve submarine to-air communication.

4.2.6 Category S. OPTICAL ENVIRONMENTAL

In the Introduction it was noted that this technology was restricted to fluorometry. Fluorescence is the emission of a longer wavelength light by a molecule or atom irradiated by light of a shorter wavelength. In essence, a photon is absorbed, stored briefly, and emitted at lower energy. Whereas spectrophotometers and colorimeters operate by transmission, a flourometer is usually arranged to detect the emitted light at some angle (say 90°) to the incident light. The advantages of fluorometry over colorimetry are increased sensitivity, increased specificity, and linearity of response. The sensitivity increase is a result of the fluorescent effect increases from zero as material of interest is added while the colorimeter reading decreases from 100%. That is, the colorimeter measures the transmission of light and yields some measure of absorption at the incident wavelength, while the fluoremeter measures absorption and subsequent re-emission at a longer wavelength. Unlike colorimetry, the sensitivity of fluorometry can be increased simply by increasing the sensitivity of the light detector. Since the calibration curve of a colorimeter is fixed for a given optical path, the same sensitivity increase is not possible. While the colorimeter signal decreases with concentration of the material of interest, the fluorometer signal obviously increases since more light is re-emitted as more light is absorbed. The fluorometer signal is also linear with concentration; a corresponding increase in light emission results from each increment of fluorescent material in the sample. The colorimeter, however, follows Beer's law, a negative exponential. The increased specificity of fluorometry vice colorimetry is due primarily to the relative scarcity of fluoroscent vice colored materials. But the specifity is also enchanced by the lesser effect of particulate matter on fluorometry. Finally, since two wavelengths are involved in fluorometry, it is

often possible to discriminate between materials that have similar wavelength absorption sharacteristics but different fluorescent emissions.

While fluorometry can utilize fluorescent dyes to measure flow or dilution on large scales (parts per trillion are possible) the relevant uses here are the detection of chlorophyl in even the least productive ocean waters (below 0.05 milligrams per cubic meter), the detection of oil within the water column (changes of 2 parts per billion), and suspended solids monitoring. The latter utilizes a nephelometer modification of a fluorometer and has the same advantages over a turbidimeter or transmissometer that a fluorometer enjoys over a colorimeter or spectrophotometer.

4.3 Category T. MAGNETIC FIELD

Modern magnetic field sensors which are used to detect anomalies in the background field of the earth such as might be produced by submarines, local geological features, or even communication signals, fall into four general categories. The first is the fluxgate sensor, the second and third are magnetic resonance sensors, excited in different ways, and the fourth is the superconducting quantum interference sensor, or SQUID. The unit of measurement in widest current use is the nanotesla (nT), an International (SI) unit equal to 1 gamma, or 1×10^{-5} gauss. These sensors when used underwater are normally called upon to detect fields in the range of 10^{3} nT to 10^{-3} nT. The former is encountered near sunken hulls or large geological features and the latter is typical of the level of background geomagnetic noise on a magnetically quiet day.

In the sections which follow, the operating principles of each type of sensor are described.

Fluxgate sensor; The fluxgate was developed first, originally for geophysical prospecting purposes. It is inherently directional, being sensitive only to the field component parallel to its axis, and it must be calibrated; that is, it does not give an absolute reading of the field as the resonance devices do. As a result it is frequently used only to sense changes in direction, and appears as the sensitive element in intrusion alarms, drift compensation circuitry for gyrocompasses, and heading sensors. It has been used in the past in airborne magnetometers for submarine detection (AN/ASQ-8,/ ASQ-10) but these are being supplanted by optically pumped instruments. Unlike the resonance devices the fluxgate requires relstively little power to operate. It is this feature which has made it attractive for use in space probe vehicles where measurement of planetary magnetic fields is desired. In this mode a three-axis device is used so that both the magnitude and direction of the field can be read. Resolutions of the order of 0.1 nT can be achieved, but 1 nT is more typical.

The principle of operation is as follows: A magnetic core made of material with a sharp saturation characteristic and low hysteresis is wound with a primary coil which is driven by an alternating current sufficiently strong to push the core into saturation in both directions. This saturation causes the vpltage induced in a secondary winding to have the form of a clipped sinusoid. In the presence of a field, this clipping will be asymmetric, and it can be shown that the second-harmonic content of the clipped waveform is directly proportional to the strength of the external field. Physically, the core can be a single cylinder, a pair of long thin plates, or a torus whose plane is set parallel to the field. The device can be further simplified by winding the coils in opposition so as to read the second harmonic directly, without the use of filters. Each configuration has its advantages, but the

toroidal form is probably the most widely used at present. Field readout is continuous, the sensing elements are small and rugged, and the device is well-suited to operation under adverse environmental conditions.

Resonance sensors: The magnetic resonance devices are very widely used at the present time, especially for detection of underwater magnetic anomalies. They have two advantages over the fluxgate: their sensitivities are 1 to 2 orders of magnitude higher and they measure the field absolutely; no calibration or compensation circuitry is necessary. On the other hand, they do not readily measure direction, and in fact any directional anisotropy present in a given design is minimized in order to increase field-strength sensitivity.

There are two different types of resonance sensors in use: one employs protons which are caused to precess in an external field, and the other makes use of optical excitation of atomic electrons to energy levels which are perturbed by the external field. In the proton case sensitivities in the range of 10^{-1} - 10^{-2} nT are obtainable, but at the expense of allowing long (many seconds) counting times between readings. The optical sensors are considerably more sensitive (10^{-2} - 10^{-4} nT), and can be read continuously, but geomagnetic background noise imposes an operational limit. As a result these sensors, like the SQUIDs described below, are frequently used in pairs as gradiometer elements so that background noise common to both can be cancelled out.

The operating principles of the two types are similar, but important differences exist, and devices which use the resonance phenomenon differ widely. A typical proton resonance instrument consists of a cell filled with a substance rich in hydrogen, such as water or kerosene, surrounded by a coil of wire which is capable of producing a large magnetic field. When this field is turned on, the protons, which have a magnetic moment, precess about the field and produce a net magnetization in the direction of the field. When the field

is removed the protons relax to a random alignment again by precessing about the direction of any background field which may be present. The frequency of this precession is directly proportional to the strength of the background field, the constant being 0.0426 hz/nT. Since a very large number of protons is involved, the field induced by this precession can be detected and its frequency measured. Because the constant of proportionality, the gyromagnetic ratio, between frequency and field is made up of fundamental physical constants, the field can be determined in an absolute sense; no calibration is necessary. The earth's field, for example, produces a precession frequency of the order of 2 Khz, so changes of the order of a nT can be detected if the frequency can be sampled for a period of several seconds. This means that field readouts are not continuous.

As an underwater sensor the proton magnetometer has two other disadvantages; the magnetizing field consumes considerable power while it is turned on, and only measurements of magnitude, not direction, of the field vector can be made.

The optically pumped magnetometers also make use of a resonance phenomenon but the moments involved are those of the electrons in optically excited atoms. Because the mass of the electron is so much smaller than that of the proton, the gyromagnetic ratio is considerably higher, but the proportionality is not direct because of coupling between the electron and its parent atom.

In these magnetometers the electronic magnetic moments are aligned by means of optical pumping. Circularly polarized light from an ionized gas or vapor is directed through a non-ionized atmosphere of that vapor and is selectively absorbed by it. That is, the electrons are raised to an excited state in their parent atoms. If the vapor is in a magnetic field this state is further split into two sub-levels whose separation is proportional to the

strength of the field. The sense of the circular polarization is chosen so as to populate the upper level much more densely than the lower - a pumping process - and the frequency of the radiation which the atoms emit as the electrons drop back to the lower state is proportional to the level separation and hence the field. This radiation falls in the megahertz range for the earth's field (vice kilohertz for proton resonance) and sensitivity to small changes in field is enhanced accordingly. For cesium vapor the constant is 3.498 hz/nT and for helium it is 28.0 hz/nT. Furthermore, these transitions take place continuously and the field readings can be continuous as well. Like the proton sensors, the optical sensors provide absolute field values.

At these sensitivities the background fluctuations of the earth's field impose a practical limit on the capabilities of actual measuring instruments. In order to circumvent this a pair of sensors is usually constructed so as to cancel out the effects of noise common to both, and the gradient of the field, rather than its absolute value, is measured. This is usually the property of interest in any case, both in geophysical and military applications.

Superconducting (SQUID) Sensors. With the discovery of flux quantization in superconductors in the early 1960's, a new kind of magnetic field sensor became feasible. This is the so-called SQUID (Superconducting Quantum Interference Device). Its operation is based on the fact that magnetic flux enters or leaves a closed loop of superconducting material in finite steps, or quanta, of a size equal to $h/2c = 2 \times 10^{-15}$ webers. A SQUID field sensor, therefore, consists of a ring of superconducting material constructed with a weak link - a thin barrier ($\sim$50 microns) of insulating material which interrupts the flow of current in the ring whenever it reaches a critical value. At smaller currents quantum mechanical tunneling across the barrier allows the current to flow unhindered.

The strength of this current is ordinarily proportional to the size of the magnetic field in which the SQUID ring is placed. If the field is increased to the point where the current becomes critical, the link momentarily opens, the current stops, and a flux quantum slips into the ring. This has the effect of lowering the external field slightly, the link closes, and current flows again. A pickup coil wound around the SQUID can sense this flux jump, and thus the number of quanta passed in (or out, for decreasing fields) of the loop can be counted and the total field change determined.

By means of circuitry involving a driving field in the rf range superposed on the external field of interest, and a feedback coil arrangement which keeps the SQUID at a point of optimum sensitivity, changes in the external field of the order of 10^{-3} - 10^{-4} nT can be detected. This makes the SQUID an excellent field-change detector, but like the optical devices, ambient background noise can be troublesone. Accordingly, gradiometer configurations are usually employed, and because the separations between SQUID elements can be kept small, three-axis orthogonal sensors can be constructed. These can yield not only the magnitude of the field change, but its direction as well. This means that the location of the magnetic disturbance can in principle be determined if inputs from an array of such gradiometers can be collected and processed.

The major disadvantage to the device is its cryogenic cooling requirements, but long-term storage of liquid helium is a well-developed technology and operating times of the order of weeks have been achieved in practice.

4.4 Category U. ELECTRIC FIELD

The only underwater system which makes use of a remotely-sensed electric field is a diver communication system. It was originally developed by

Farallon Industries and is currently being manufactured by the Technology Development Corporation under the trade name Hydrocon. Typical underwater ranges are only of the order of 120 meters, but these can be indefinitely extended by transmitting to a surface buoy and relaying the message by conventional radio either to a mother ship or to another buoy and thence back into the water. This latter technique is most useful when two groups of divers are working some distance apart.

The main advantage to the system is that it is relatively insensitive to environmental variations in the water medium. Acoustic systems, while capable of much greater range, are strongly affected by refractive disturbances and internal reflections (multipath), and are seriously degraded in performance by biological scattering, particulate turbidity, and background noise. The developers of the electrical system claim that it receives messages with near-telephone clarity and environmental effects are very small.

The system is contained in a pressure cannister rated to 300 feet and carried by the diver as part of his SCUBA backpack. It contains batteries. a voice activated transmitter, and a receiver which responds directly to the audio frequency signal received by the antenna. No carrier frequency is used. A pressure compensated microphone and a bone-conduction earphone are built into the diver's face mask and the antenna runs from the cannister to a clip on the diver's ankle.

The antenna pattern is that of a conventional dipole whose length is small compared to the wavelength being transmitted, and signal strength at the receiver therefore depends on the relative orientation of the two antennas. This directionality is not generally desirable, but it is useful in the case where a diver must be located by his fellows in low-visibility water. The

null in the dipole pattern provides a homing point. The system has been tested not only for voice communication but for data transmission as well. It has worked quite satisfactorily in this mode, but range remains the major limitation.

4.5 Category V. ELECTROMAGNETIC/ENVIRONMENTAL

As noted earlier this category consists of sensor systems not utilizing optics or acoustics. These electromagnetic devices comprise an almost miscellaneous category of environmental sensors. Included are systems for temperature, pressure, salinity, flow (including direction), and pH and other ion detectors.

Almost all ocean temperature sensors operate on the principle of resistance change with temperature. By far the most common thermal resistance element used is a thermistor. Some of these are used with circuitry which linearizes their response. While the response time of thermistors is reasonably fast, on the order of 30 ms, stability and drift are problems. The more accurate platinum resistance thermometers are more stable but have a slower response, on the order of 350 ms. At least one company utilizes circuitry which claims to give temperature data with the accuracy of a platinum resistance thermometer and the speed of a thermistor. Processing of the data is available at several levels of sophistication. A typical system might employ electrical signals derived from bridges and applied to voltage controlled oscillators to obtain as fm frequency analog of the measurement for telemetering. One manufacturer of thermistor chains employs analog to digital conversion with subsequent acoustic transmission to the surface. Another unit uses AC signal conditioning amplifiers with large feedback ratios and stable and precise ratio transformers before AC analog-to-digital conversion. Such a system

might scan the temperature at other sensors 30 or so times a second. In another case a period measurement of a Wein bridge oscillator output yields a resolution of 0.05-0.1 m °C/ bit at a 3 hertz sampling rate. Drifts as low as $\pm$0.01°C over a six month period are guaranteed. At least one development is underway of rock-stable circuitry (beyond the sensor) which is checked and adjusted if necessary before each sensor reading. Preliminary information mentions non-drifting bridges that compensate for sensor drift. Besides the resistance effect, specially cut quartz crystal oscillators with a large temperature coefficient have been used as temperature sensors. Since frequency counting is usually employed for these there is an obvious trade-off between response/reading time and sensitivity.

Although quartz crystals are used as pressure sensors, most ocean systems employ strain gage transducers. These may be compensated for both zero and sensitivity shift with temperature. Again, various levels of sophistication in signal processing may be found which result in accuracies as high as 0.1 decibar or .05% of full scale for the final instruments.

Almost all conductivity (or salinity) measurements are made with electrodeless induction cells, that is, toroidal transformers coupled by a seawater loop. One company uses a miniature four-electrode conductivity cell while another employs a three-electrode, two terminal device. A period measurement of the latter yields a sensitivity of 7×10^{-5} mmho/cm with a typical drift of 0.003 mmho/cm/month.

Many flowmeters are of the mechanical rotor type and operate by counting rotations and sensing the direction of rotation. A vane may be utilized to indicate the direction of flow which is then compared to a compass. Typical specifications for these are $\pm$ 2 cm/s or 2% of the reading up to 500 cm/sec. Current direction is usually specified to 3° or so. Acoustic flowmeters were

discussed in Category M. Acoustic Environmental. Electromagnetic flowmeters are available which operate on the Faraday principle that a conductor such as water moving in a magnetic field produces a voltage that is proportional to the water velocity. One company has developed a spherical probe containing an electromagnet and two pairs of external electrodes in contact with the water. Flow around the probe intersects magnetic flux lines and generates voltages which are detected by the electrode. Processing then yields analog voltages linearly proportional to the X and Y components of the velocity vector, and the velocity magnitude and direction are then computed. Ranges up to $\pm$ 300 cm/sec are available with a claimed accuracy of $\pm$ 2%.

Measurement of pH usually is done with a calomel combination electrode which generates an electrical current proportional to the pH value of the water. When this voltage is applied to a voltage controlled oscillator an fm analog signal is generated. Accuracy claimed varies from $\pm$ 0.05 pH units between 6 and 9 to $\pm$ 0.2 pH units between 2 to 14. We recall that pH7 represents a neutral hydrogen potential.

4.6 OTHER ACOUSTICS

4.6.1 Category W. ACOUSTIC BUOYS (SONOBUOYS)

Sonobuoys are miniature sonars, active, passive or both, that are usually air launched and monitored via an RF link from an airplane. They are expendable and are deliberately scuttled after use. The altitude of the launch vehicle may be as great as 40,000 feet with a speed up to 425 knots for the passive units but the active sonobuoys appear to require slower speeds (up to 250 knots) and lower altitudes (up to 10,000 feet). Air descent is slowed and controlled by a drogue parachute or rotochute which is jettisoned upon water entry. At the same time a flotation bag may be inflated and a vhf or uhf

transmitting antenna erected. The watertight sonobuoy housing itself descends to a preselected depth. Power is supplied by a seawater activitated battery. After a preselected time intermal the sonobuoy is turned off and eventually caused to sink, usually by means of a seawater-soluble plug that floods the unit upon dissolution.

A simple passive sonobuoy might have no directional capability and so require the development of several units for target location. Newer passive sonobuoys employ directional hydrophones and have built-in compasses so that bearing information can be transmitted to the airplane. The audio frequency range of a simple passive unit might be 10 to 10,000 hertz with the rf transmission set between 162.25 to 173.50 MHz. A "sound reference sonobuoy" utilizes a calibration permitting the determination of underwater acoustic sound pressure levels up to 20 kHz.

Active sonobuoys are complex sonar systems which both send and receive sound signals underwater. The sonar mode might be automatic keyed cw, pulse cw, or linear fm. A simple active unit employing an automatic keyed cw sonar mode can be effectively operated over a 0 to 10 nautical mile range from an altitude of 500 feet in sea state 5 conditions. A more sophisticated system such as DICASS (Directional Command Activated Sonobuoy System) operates both actively and passively under command of the aircraft. This command capability includes deep depth selection, scuttle, and selection of sonar transmission signals. Sonar echoes from the selected activating signal are multiplexed before transmission to the aircraft.

A variation of the expendable air-droppable sonobuoys described above is the long life deep moored buoys which can utilize automatic mooring. This can have in-buoy processing or data storage and can be used in very long range buoy data links.

4.6.2 Category X. ACOUSTIC ARRAYS

This category is limited to towed line arrays. As discussed elsewhere, the advantages accruing to the use of a streamer array stem basically from the large acoustic aperture made available by this technique. This yields enhanced selectivity in both directionality and signal-to-noise ratio. By locating the array far to the rear of the towing vehicle it is possible to restrict the noise picked up in the band of interest to that generated by the water flow past the towed array itself. Towing speeds may be as great as 15 knots.

Apart from the military classified arrays, these streamers range from the seismic exploration Minimarine system offering quick-disconnect coupling and 24 trace capability in a 1.4 inch diameter vinyl tube of some 50 m active length to the MESH (Multi Element Streamer Hydrophone) arrays. These may have up to 200 hydrophone elements divided into four acoustically isolated sections of 50 elements each. The elements in each section are generally connected in parallel, although for some applications a series connection is utilized. These MESH arrays are 2.5 cm in diameter. Their depth capability is 1800 m and their frequency response is 0.5 to 3000 Hz ($\pm$ 0.5dB). The 50 element "building block" is some 7.6 m long. Directivity of the individual elements may be omnidirectional in the horizontal plane or radially omnidirectional.

Progress has been made in miniaturizing these acoustic arrays which have been constructed with hundreds of channels. Of course, the full utilization of such arrays requires not only multiplexing but sophisticated signal processing and beamforming techniques. These are addressed in the next category.

4.6.3 Category Y. ACOUSTIC PROCESSORS/BEAMFORMERS

Only through sophisticated signal processing can the full utilization of multi-elements towed acoustic arrays be realized. Although a limited number of elements may be handled by separate, dedicated wiring, the more satisfactory method of receiving individual element array signals for processing is via multiplexing. By their nature, line arrays constitute a passive sonar and so received signal beamforming only is under consideration here.

Beamforming processing was initially implemented mechanically by modifying steering weights on the elements of an array, by varuatuib if the separation of elements, by shading, and by simple sidelobe cancellors, but in order to form steerable beams electronic processing is necessary. Such processing involves dedicated minicomputers, and a number of other routines can be used as well, such as input channel signal conditioning, Fast Fourier Transform (FFT) spectrum analysis, either conventional or adaptive beamforming, and inverse FFT for interfacing with existing field equipment and for display formatting.

4.7 Category Z. CHEMICAL

Although fluorometryu could be listed as a chemical technology, it has been included under OPTICAL-ENVIRONMENTAL. The only item under this category Z is the "Sniffer" offered by Inter Ocean Systems, Inc.

The SNIFFER system employs a towed instrument body deployed just above the sea bottom and towed at speeds up to 10 knots. The underwater instrumentation consists of salinity, temperature, and depth sensors, a high resolution bottom-looking sonar, and an electromagnetic current sensor, in addition to the pumping system which continuously pumps seawater to the surface. The system provides continuous analysis of the dissolved hydrocarbon gases, methane,

ethylene, ethene, propane, isobutane, and n-butane. As the higher molecular weight hydrocarbons are not produced in significant quantities by ongoing biological processes, they are interpreted as indicators of petroleum deposits. The false signals from recent natural and man-made sources, moreover, are identified by their characteristic hydrocarbon ratios.

The final products of a SNIFFER survey are contour maps delineating areas with natural petroleum and gas seeps. Since sampling is conducted below the thermocline the plumes which are formed by minute seeps and are transported by marine currents are routinely detectable 10 to 20 km from their source area and can be traced back to the source. The sensitivity of the analyzer permitting such detection is on the order of 5×10^{-9} ml gas per ml water. This permits reconnaissance surveys to be made with line spacings on the order of 20 km. Detailed work requires line spacings no less than one or two km.

4.8 Category AA - FIBER-OPTIC TECHNOLOGY

An intensive effort is under way to develop underwater sensors based on the properties of optical fibers. In particular, the development of a family of fiber optic hydrophones is of great interest, and sensors for other energy fields, e.g., temperature and magnetic field, have been demonstrated in the laboratory. At this writing (1980) no underwater sensors based on fiber optic properties are yet in routine use, although pilot models of a number of devices have been built. Because the application of fiber optic techniques to underwater sensor problems is expected to have far-reaching effects, especially in acoustics, the following overview is provided. The field is developing very rapidly, so no attempt is made to predict what specific systems will be available in 1990 or 2005, the two reference points for the other sections of this study.

It has been known for some time that transparent fibers which have dimensions of the order of a few wavelengths of light act like waveguides for the light, with modal structures quite analogous to those observed in waveguides commonly used for microwave transmission. However, losses due to absorption and scattering originally limited the useful length of such fibers to the order of meters. With the development in the early 70's of low-loss fibers, path lengths of kilometers suddenly became feasible. At about the same time cladding techniques were developed which made it possible to adjust the value of refractive index across the face of the fiber in such a way as to minimize leakage losses and incidentally to improve mechanical properties as well. At present losses of 1 db/km and tensile strengths of 100,000 psi are common and fibers with even better parameters can be obtained.

Current research is divided between two major areas, the development of sensor devices per se, and the development of optical circuit elements necessary to manipulate and process the signals: detectors, amplifiers, couplers, multiplexers, and numerous electric/optic interface devices. The ideal system is visualized to be all-glass, that is, the signal, once generated, is processed and displayed without having to pass through any intermediate electrical stages. However, operational systems likely to be of interest in the near term will probably be hybrid in nature. Because this report is concerned primarily with sensors, discussion of fiber optic circuitry will not be carried further, but developments in this area should be considered the pacing elements in fiber optic system technology today.

All acousto-optic hydrophones are based on one of two effects, acoustically induced phase shifts or intensity fluctuations in a beam of light. For the former, optical interferometry must be utilized to convert the phase modulation to intensity modulation, but the inherent sensitivity is higher.

The sensor which has the highest sensitivity and has aroused the most interest is an interferometric device which consists of a coiled fiber a few tens of meters in length. A coherent beam of light, generated typically by a single-mode AlGaAs solid-state laser, is passed through this coil and also through a reference fiber which is not exposed to the acoustic field. The action of the acoustic pressure wave on the coil is to change both its refractive index and its length, and the phase of the emerging light, measured with respect to that from the reference fiber, is changed accordingly. (The shift due to index change is opposite to that due to length, but the latter dominates.) The magnitude of the shift increases with the length of the fiber, and sensitivity is limited in principle only by attenuation in the fiber and its ability to preserve single-mode transmission over the full distance. Neither are serious problems for the current state of the art. A sensor of this type, consisting of 10 meters of fiber and with a power throughput of 1 milliwatt, should be capable of detecting a signal pressure level of 4db re 1μPa, a level well below that of sea-state zero for all frequencies of interest. Actual sensors have approached this figure in the laboratory, and it is already apparent that usable sensitivity will be determined by the environmental background and not the sensor itself.

An example of a sensor which operates directly on intensity variations produced by the incoming sound is the moving grating sensor. Two gratings are involved, one stationary and one movable, arranged to form a shutter. The movable grating is attached to a diaphragm which is excited by the incoming sound and light passing through the two gratings is modulated in intensity. The optical fiber in this case simply acts as a transmission line, and ordinary incoherent light, typically from a light-emitting diode, can be used. The

sensitivity of this device, measured as above, should be about 12 db re 1μPa which is still below sea state zero.

Other acoustic sensors have been demonstrated which depent on light leakage, multiple reflections between plates, critical-angle reflections, etc., but their sensitivities tend to be considerable lower and each has vulnerabilities of its own.

The most serious problem with the interferometric sensors is that the optical properties of the fiber are not solely dependent on pressure. Temperature dependence in particular is very strong, and thermal fluctuations, especially slow ones, can produce serious background effects which may require additional signal processing to suppress. On the other hand, this sensitivity can be exploited to produce a temperature sensor (which must in turn be shielded from pressure fluctuations) of considerable value. This has not to date been explored as thoroughly as the acoustic sensor configurations, but work is in progress. Typical phase shifts are of the order of 80 radians/°C for a one-meter fiber - a very large effect.

Considerable work is being done to produce a towed acoustic array composed entirely of fiber optic elements. This entails not only the acoustic transducer problem itself but also optical signal processing and the development of a suitable multifiber tow cable. The great advantage to such a system is compactness - fiber optic cables are only a fraction of the size of their electrical equivalents. Many problems remain to be solved in order to meet a target date of 1983 for a prototype system.

Another area of intense interest is the development of motion sensors of the ring-laser variety, but with the optical path length increased by one or two orders of magnitude. Such devices have reached the laboratory-prototype stage and will probably be marketed in the next few years. A major difficulty

appears to be in the limited ability of a single-mode fiber to maintain the polarization of the incoming light over the necessary distance; repeated internal reflections tend to change linear polarization to elliptical. This is mainly a materials problem and improvements can be made, but full realization of the potential of the technique may be delayed.

Another sensor of interest is a fiber optic magnetometer. This too depends on fiber length and is proposed in two different forms. One is to make the fiber out of glass which contains a magnetic additive of such a nature that the plane of polarization of the light in the fiber is rotated if the fiber is in a magnetic field (the Faraday effect). Another approach is to clad the fiber in a magnetostrictive material such that it will stress the fiber when placed in a field, and the length of the fiber will be changed. Both methods have advantages and drawbacks, but the magnetostrictive approach appears to promise higher sensitivity; both are still in the laboratory stage.

Chapter 5. REPRESENTATIVE CURRENT SYSTEMS

The following list of underwater remote sensing systems is intended to be representative only and not exhaustive. An attempt has been made to avoid undue emphasis on the products of any single manufacturer or group thereof, but obviously the compilaton cannot but help reflect the relative cooperation of the many organizations contacted. The original letter requesting factual information is included in this report as Appendix A. Nowhere in this report have participating (or indeed, non-participating) organizations been singled out. Any conclusions drawn are those of the reader.

The listed acquisition costs are approximate and may not always include accessories.

5.1 ACOUSTICS

5.1.1 Category A. OBSTACLE AVOIDANCE SONAR

Manufacturer	Ametek, Straza Division
Unit	500A CTFM Sonar
Full scale range	50, 150, 500, 1500 yds
Range resolution	2% of full scale
Lateral resolution	$\sim$ 1/30 of range
Display	PPI (+ Audio)
Depth	20,000 ft
Frequency	87 to 72 kHz sweep
Sweep periods	0.375, 1.125, 3.75, 11.25 seconds (depending on range)
Scanning: auto	$\pm$ 150°
sector	$\pm$ 30°
manual	$\pm$ 225°
Scan rate	$\sim$ 30°/s
Projector beamwidth	
horizontal	60° $\pm$ 5°
vertical	17° $\pm$ 1.5°
Hydrophone beamwidth	
horizontal	2.5 $\pm$ 0.5°
vertical	15 $\pm$ 1°
Cost	$64.K

Manufacturer		Ametek - Straza Division
Unit		250A CTFM Sonar
Maximum range		20, 75, 200, 750, 2000 ft
Range resolution		2% of full scale
Lateral resolution		$3° \pm 1°$
Display		PPI
Depth		3000 ft
Frequency		107-122 kHz
Scanning	auto	360°
	sector	$\pm 45°$
Scan rate		30°/s
Cost		$23.K

Manufacturer	Ametek - Straza Division
Unit	300 SWAP Sonar
Range	1-500 yds
Range resolution	0.8 yds
Lateral resolution	Not specified (see beamwidth)
Display	sectored PPI
Depth	600 ft
Frequency	200 kHz
Sweep Periods	
Scanning fixed	120°
Scan rate	2 kHz
Projector beamwidth	
horizontal	120 ± 10°
vertical	16° ± 2°
Hydrophone beamwidth	
horizontal	3° ± 0.5°
vertical	15° ± 1.5°
Cost	$35.K

Manufacturer	EDO Western Corp.
Unit	4059 OAS-1 Sonar
Full scale ranges	25, 50, 100, 200, 400 m
Range Accuracy	± 2%
Lateral Accuracy	Not specified (see beamwidth)
Display	TV, sector, memory or continuous (side scan mode available)
Depth	6000 ft (20,000 ft optional)
Frequency	100 kHz
Pulse length	0.1 ms
Scan	± 30, ± 45, ± 60, ± 90°
Scan time	2.5 - 58 sec.
Beamwidth horizontal	2°
(@3dB) vertical	50°
Time Variable Gain	Compensation for spreading and attenuation
Cost	$38.5K

Manufacturer	Electrospace
Unit	STARNAV
Range	25-600 m
Range accuracy	Not specified (see pulse length)
Lateral accuracy	Not specified (see beamwidth)
Display	Forward "side scan type" format
Depth	3000 psi (10,000 psi opt.)
Frequency	100 kHz
Pulse length	100 μs
Scan	180° - sector ± 30, ± 45, ± 60, ± 90°
Scan time	0.13 to 0.66 sec/degree
Fan beam (3dB)	
horizontal	1.5°
vertical	65°
Time Variable Gain	Yes
Cost	$61.K

Manufacturer	International Submarine Technology, Ltd.
Unit	ESTB Sonar
Range scales	20, 80, 320 m
Range accuracy	0.5% of full scale
Lateral accuracy	Not specified (see beamwidth)
Display	TV "B" Scan
Depth	3000 ft., full ocean depth optional
Frequency	150 kHz
Pulse Length	Not specified (see range accuracy)
Pulse Rep rate	30, 7.5, 1.875 Hz (depends on range)
Scan	Mechanical 30° or 90° sector
Scan rate	0.5, 1, or 2° per ping
Transmitter beamwidth	
horizontal	6.5°
vertical	12-50°
Receiver beamwidth	
horizontal	2.3°
vertical	12-53°
Cost	$50.K

Manufacturer	UDI/Highland Offshore Services Group
Unit	AS360 Scanning Sonar
Full scale ranges	20, 40, 100 m
Range resolution	75 mm
Angular resolution	1.15° (500 mm @ 50 m)
Display	PPI or B scan
Depth	1000 ft
Frequency	500 kHz
Pulse Length	Not specified (see range resolution)
Scan	360° or 10 to 320° sector
Scan rate	8.6°/min, 21.5°/min, 43°/min
Transmitter beamwidth	
horizontal	1.2°
vertical	30°
Receiver beamwidth	
horizontal	3°
vertical	30°
Cost	$20.k

Manufacturer	WESMAR
Unit	SS230
Ranges	30-1650m
Range resolution	
Lateral resolution	Not specified (see beamwidth)
Display	CRT, A scan, B scan, modulated
Depth	Ship mounted
Frequency	60 kHz
Sweep periods/pulse length	adjustable
Scanning	Automatic 360° or sector
Scan rate	
Beamwidth	9° stabilized, tiltable
Time Variable Gain	Yes
Cost	$12.7K

Manufacturer	WESMAR
Unit	SS165
Range	15-720m
Lateral resolution	Not specified (see beamwidth)
Display	CRT - A scan, B scan, modulated
Depth	Hull Mounted
Frequency	160 kHz
Sweep period/pulse length	adjustable
Scanning	360° or sector
Beamwidth	6.5° stabilized, tiltable
Cost	$6.2 K

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5.1.2 Category B. PORTABLE (HAND HELD) SONAR

Manufacturer	Ametek/Straza
Unit	DHS-2 Sea Probe
Ranges (Active)	50, 100, 200 yds
Range resolution	Not specified
Azimuthal resolution	Not specified (see beamwidth)
Output	100-2500 Hz audio output
Depth	600 ft
Frequency	95-116 kHz CTFM
Beamwidth	
Projector	17°
Hydrophone	10°
Cost	$4.3K

Manufacturer	EDO Western
Unit	384A
Ranges (active)	20, 60, 120, yds
Range resolution	Not specified
Azimuthal resolution	Not specified (see beamwidth)
Output	250-2500 Hz audio
Depth	600 ft
Frequency	160-200 kHz CTFM
Beamwidth	15°
Cost	$5.5K

Manufacturer	Helle
Unit	6400
Full Scale Ranges	60, 360 ft
Range resolution	Not specified
Azimuthal resolution	Not specified
Output	LED readout of range
Depth	1000 ft
Frequency	200 kHz
Pulse repitition rate	2400/min., 400/min. (range dependent)
Beamwidth	Not specified
Cost	$1.1K

Manufacturer	BURNET
Unit	AN/PQS-2A
Full Scale Ranges	20, 60, 120, yds
Resolution	Not specified
Output	Audio tone in earphones - frequency varies with range
Depth	300 ft
Frequency	115-145 kHz CTFM
Beamwidth	Not specified
Cost	$5.K (estimated)

5.1.3 Category C. MILITARY SONAR

This category contains classified information not generally available.

5.1.4 Category D. SIDE SCAN SONAR

Manufacturer	EDO Western
Unit	606A
Full Scale Ranges	50, 100, 200, 400 m
Resolution	Not specified (see beamwidth and pulse length)
Output	Paper chart or 15 binary levels
Depth	2000 ft (4000 ft option)
Maximum tow speed	15 kts
Frequency	100 kHz
Pulse length	100 μsec
Beamwidth	
vertical	(3dB) $50° \pm 5°$
horizontal	(3dB) $20 \pm 5°$
Time Variable Gain	Separate initial and final gain controls, 70 dB range, 2-100 ms delay
Cost	$28.6K

Manufacturer	EG&G Environmental
Unit	Mark 1B
Full scale ranges	50, 100, 125, 200, 250, 500 m
Range resolution	1/250 of full scale
Output	Paper chart
Depth rating	600 m
Maximum tow speed	15 knots
Frequency	105 kHz
Pulse length	0.1 ms
Beamwidth	
vertical	20° or 50°
(tilted down	10° or 20°)
horizontal	1.2°
Gain controls	Highlighting for search
	Subtle variations for survey
Cost	$39.K

Manufacturer	EG&G Environmental
Unit	(SMS 960)
Full scale ranges	100,150, 200, 300, 400, 500 m
Resolution	1/400 of full scale
Output	Paper chart, corrected for tow speed and slant range with water column removal (Digital tape interface available)
Depth rating	600 m
Maximum tow speed	15 kts
Frequency	105 kHz
Pulse length	0.1 ms
Beamwidth	
vertical	50°
(tilted down	20°)
horizontal	1.2°
Gain controls	Time Variable Gain and manual
Cost	$79.K

Manufacturer	Electrospace
Unit	STAR SCAN
Full scale ranges	25, 50, 100, 200, 400, 600 m
Resolution	Not specified (see pulse length and beamwidths)
Output	Paper Chart, optionally corrected for tow speed and slant range with water column elimination and sound speed-range correction. Digital uplink.
Depth rating	600 m
Maximum tow speed	15 kts
Frequency	100 kHz
Pulse length	100 μs
Beamwidth	
vertical	65°, (adjustable look angle)
horizontal	1.5°
Gain controls	Adaptive and manual, background normalization or contrast enhancement
Cost	$35.4K (+ $18K for recorder)

Manufacturer	Institute of Oceanographic Science
Unit	GLORIA
Full scale range	60 km swath
Range resolution	30 m
Azimuthal resolution	Not specified (see beamwidth)
	1 km @ 30 km range
Minimum vertical	
relief detectable	10 m
Output	35 mm film negative and analog magnetic tapes
Depth rating	50 m
Maximum tow speed	10 kts
Frequency	6.2 and 6.8 kHz, 100 Hz linear FM
Pulse length	4 s
Beam width	
vertical	30°
horizontal	2°
Cost	$3.M +

Manufacturer	International Submarine Technology, Ltd.
Unit	SEA MARC I
Full scale range	5 km swath (600-1000 m off bottom)
Range resolution	20 cm
Azimuthal resolution	Not specified (see beamwidth)
Output	DMA interface
Depth rating	Full ocean
Maximum tow speed	10 kts
Frequency	27 and 30 kHz
Bandwidth	5 kHz
Beamwidth	1.7° horizontal
Cost	$250.K

Manufacturer	Klein Associates Inc.
Unit	520 System, long range
Range swath	800-1200 m
Range resolution	Not specified (see pulse length)
Output	Paper Chart, optional correction for tow speed and slant range with water column removal. Digital processor available.
Depth rating	2290 m (12,000 m optional)
Maximum tow speed	16 kts
Frequency	50 kHz
Pulse length	0.2 ms
Beamwidth	
vertical	40°
(tilted down	0°. 10° or 20°)
horizontal	1.5°
Cost	\$29.5K (+ \$20.K for Correction Module)

Manufacturer	Klein Associates Inc.
Unit	520 System - General Purpose
Range swath	400-1000 m
Range resolution	Not specified (see pulse length)
Output	Paper chart with optional correction for tow speed and slant range with water column removal. Digital Processor available.
Depth rating	2290 m (12,000 m optional)
Maximum tow speed	16 kts
Frequency	100 kHz
Pulse Length	0.1 ms
Beamwidth	
vertical	20° or 40°
(tilted down	0°, 10°, or 20°)
horizontal	1°
Cost	$29.5K (+$20.K for Correction Module)

Manufacturer	Klein Associates Inc.
Unit	520 System - Very High Resolution
Range swath	50-200 m
Range resolution	Not specified (see pulse length)
Output	Paper chart, optional correction for tow speed and slant range with water column removal. Digital Processor available.
Depth rating	2290 m (12,000 m optional)
Maximum tow speed	16 kts
Frequency	500 kHz
Pulse length	0.02 ms
Beamwidth	
vertical	40°
(tilted down	10°)
horizontal	0.02°
Cost	$29.1K (+ $20.K for correction module)

Manufacturer	UDI/Highland Offshore Services
Unit	AS 350A
Range swath	Recorder has 3000 m scale
Range resolution	Not specified (See pulse length)
Output	Paper chart, analog or digital tape
Depth rating	762 m
Maximum tow speed	6 kts
Frequency	48 kHz
Pulse length	150 ms
Beam width	
vertical	60°
horizontal	1.7' or 3.2'
Gain controls	Coarse and fine, manual Time Variable Gain 80 dB range
Cost	$48.5K

Manufacturer	WESMAR
Unit	500 SS
Full scale ranges	30, 45, 75, 120, 180, 300, 480 m
Range resolution	Not specified (See pulse length)
Output	Paper chart
Depth rating	77 m
Maximum tow speed	Not specified
Frequency	105 kHz
Pulse length	Adjustable 100 to 500 μs
Beam width	
vertical	30°
horizontal	1.5°
Gain Controls	Near and far highlight
Cost	$6.5K

5.1.5 Category E MAPPING (MULTI-BEAM SONAR)

The only non-military multi-beam sonars available are manufactured by General Instrument Corporation, Electronic Systems Division, Harris Laboratory.

Manufacturer	General Instrument Corp./Harris Laboratory
Unit	Hydro Chart
Depth rating	Hull mounted
Sounding depth	3 to 620 m
Swath width	2.5 times depth
Frequency	36 kHz
Pulse length	1 to 24 ms, automatically adjusted for depth
Beams formed	21 contiguous 5° beams symmetrically arranged perpendicular to the ship's axis. Fore and aft beam dimension is either 5° or 20°.
Output	Real time contour display with speed, positioning, tide, heave/roll/pitch compensation.
Cost	$375.K

Manufacturer	General Instrument Corp./Harris Laboratory
Unit	SEA BEAM
Depth rating	Hull mounted
Sounding depth	11,000 m
Swath width	80% of depth
Frequency	12 kHz
Pulse length	7 ms
Beams formed	16 contiguous beams symmetrically arranged perpendicular to the ship's axis. The beam dimensions are 2 2/3° X 2 2/3°.
Output	Real time contour display with positioning, speed, tide, heave/roll/pitch compensation
Cost	$850.K

Manufacturer	General Instrument Corp./Harris Laboratory
Unit	SEA BEAM II

See Company for towed version of SEA BEAM

Manufacturer	AmetekStraza
Unit	WABMS

See Company for proprietary proposal of wide area bottom mapping system based on their SWAP sonar (AN/WQS-1).

5.1.6 Category F. SYNTHETIC APERTURE SONAR

This category contains classified information not generally available.

5.1.7 Category G. PARAMETRIC SONAR

This category contains classified information not generally available.

5.1.8 Category H. ACOUSTIC IMAGING/HOLOGRAPHY

There is no currently available underwater acoustic holography system. However, a Naval Ocean Systems Center (NOSC) development is included here as an example. It should be noted that the only real differences among focused acoustic imaging, beamforming acoustic imaging, and holographic acoustic imaging lies in the order in which the several requisite operations are carried out. For focused acoustic imaging the order is: spatial processing (focusing), transduction, and detection. For beamforming acoustic imaging the order is: transduction, spatial processing (beamforming), and detection. For holographic acoustic imaging the order is: transduction, detection, and spatial processing.

Acoustic Imaging System (NOSC)

(range-gated holographic acoustic imaging)

Range	5 - 100 ft
Resolution	0.3 degree (5 mr)
Transmitter	250 w @ 642 kHz
Hydrophone	48 by 48 PZT array (2304 channels)
Transmit gate	1 μs - 1s
Range gate	1 μs - 1s
Receive gate	1 μs - 1s
Field of View	11° X 10°
Depth Rating	3658 m (Pressure-tolerant electronics)
Image frame rate	1 per 2 sec (limited by computer capability)
Image dynamic range	32 dB

5.1.9 Category I. ACOUSTIC POSITIONING/NAVIGATION

It is necessary to divide this technology into sub-categories as follows:

- I-1. Acoustic Positioning
- I-2. Acoustic Navigation (doppler, or correlation, or contour following)
- I-3. Acoustic Releases

Category I-1. Acoustic Positioning

Manufacturer	Ametek/Straza Division
Unit	Sea Probe 270 CTFM Locator
Frequency (output)	87 to 72 kHz CTFM
Maximum full scale ranges	40 to 4000 ft in 5 scales
Range resolution	1% of full scale range
Bearng resolution	3° (locator)
	10° (marker)
Scanning	Auto 360°; 90° sector
Scan rate	24°/sec
Output	PPI and audio
Projector beamwidth	
vertical	15°
horizontal	44°
Hydrophone beamwidth	
vertical	15°
horizontal	3°
Vehicle Transducer beamwidth	
vertical	22°
horizontal	omnidirectional
Pingers	2 (@ 37 kHz and 45 kHz)
Cost	$35.K

Manufacturer	Communication Associates, Inc.
Unit	Sea Trace
Frequency	Approximately 33 kHz, 6 crystal controlled channels
Range	5-10 miles specified
Output	Signal level meter and audio
Pulse length	10 ms
Pinger repition rate	1 pluse/sec (coded for temperature and pressure)
Hydrophone beamwidth	
vertical	85°
horizontal	11°
Maximum platform speed	20 kts
Pingers	Up to 7
Cost	\$2.0K (+ per ultrasonic transmitter ~ \$1.K)

Manufacturer	EDO Western
Unit	4068 NAVTRAK III
System	Short Base Line
Frequencies - Interrogate	22, 23.5. 25, 26.5, 28 kHz
Reply	30, 30, 30, 30, 30 kHz
Interrogate pulse length	7 ms
Reply pulse length	5 ms
Output	Polar or Rectangular TV type with ship reference and position and transponder ID and position
Full scale ranges	25, 100, 250, 1000, 2500 m
Range accuracy	1% of full scale
Bearing accuracy	$\pm$ 0.5 to $\pm$ 4.5° (function of bearing angle in hemisphere below the vessel)
Operating depth	1000 m (higher optional)
Transponders	Up to 5 (responder mode included)
Transponder beamwidth	
vertical	60°
horizontal	omnidirectional
Operating life	1 yr. listening + 10^6 replies
Cost	$41.3K

Manufacturer	EDO/Western
Unit	462B
System	Pinger only
Frequency	10-14 kHz adjustable
Maximum operating depth	40,000 ft
Pulse length	1 ms
Pulse repition rate	1 pps
Operating life	30 hours
Activation	External switch connector
Cost	$2.3K

Manufacturer	EG&G/Sea Link
Unit	ATNAV II
System	Long Base Line
Frequencies	Interrogate - 9 and 11 kHz Reply - 7.5 to 15 kHz
Range	Up to 9 miles
Position accuracy	2 to 3 m
Output	Plot of ship (and/or responder) position relative to transponder field
Water depths	to 6000 m (Transponder depth optimized by ray trace calculation)
Transponders	Up to 16
Transponder spacing	Up to 8 km baseline (self-calibrating)
Cost	$84.K (+ transponders @ $6.K each) (Submersible Version SUBATNAV is $62.K)

Manufacturer	Helle
Unit	PR-05
System	(Combined ATR-01 Wet and PR-04)
	Time ranging transponder and short baseline bearing
Range	Up to 2 miles
Range accuracy	± 3% of meter full scale (slant range)
Output	Digital range and meter bearing
Frequencies	23-27 kHz, pulsed
Cost	$21.4K

Manufacturer	Helle
Unit	Pingers Only
Maximum range	1 to 8 km
Maximum depth	300 to 900 m
Battery life	2 days to 5 years
Frequency	12 to 37 kHz
Activation	External pinger switch
Cost	$0.2 - 1.0K

Manufacturer	Inter Ocean Systems
Unit	SPANS
System	Short baseline positioning

(No detailed specifications provided)

Cost	$40.K

Manufacturer	Honeywell
Unit	RS 902
System	Free-running beacon positioning
	Ultra-short baseline
Output	TV type position indicator
Maximum display range	16,000 m
Minimum range	30 m
Position resolution	1% of slant range at 100% of transducer depth
Maximum velocity	3.5 kts
Maximum depth	8,000 m
Depth accuracy	± 0.5% of water depth
Tilt measurement accuracy	± 0.5°
Frequency	22 to 30 kHz (9 channels)
Beacons	One
Cost	$63.0K

Manufacturer	Honeywell
Unit	RS/904
System	Ultrashort Baseline
	Free running pinger and transponder modes

(Transponder mode more accurate for horizontal offsets greater than depths and for unknown depths)

Position resolution	1% of slant range for 200% transducer depth if water depth is unknown
	1% of slant range for 400% transducer depth if water depth is known

Transponder and/or beacons - uses up to 2 transponders
displays up to 4 (including responder)

Cost	$89.K

Manufacturer	Honeywell	
Unit	RS/906	
System	Long and short-baseline	

(Long baseline offers greater accuracy for broad areas and great depths)

(Shortbaseline accuracy same as RS/904)

Long baseline accuracy	@ 22-30 kHz	1-3 m
	@ 6.25-14.75 kHz	3-5 m
Output	X-Y graphics of slant ranges to 4 transponders plus position of vessel	
Cost	$99.K	

Manufacturer	Inter Ocean Systems
Unit	SPANS
System	Long Baseline Positioning

(No detailed specifications provided)

Cost	$50.K

Manufacturer	Johnson Laboratories, Inc.
Unit	Beacons, Transponders, Receivers, Directional Hydrophones Only
Activation	Sea water energy source
Cost	
Sonic Beacons	$0.1 - 0.3K
JTR-40 Transponder	$0.4K
Sonic Receivers	$0.2 - 0.8K
ADH-38L Directional Hydrophone	$0.2K

Manufacturer	Mesotech /T. Thompson Ltd.
Unit	RR/CRT-1/Mod. 440
System	Submersible Positioning
	Long Baseline
Output	CRT display of position and path
Accuracy	± 2 m in 1500 m range
Cost	$40-45K

Manufacturer	Ocean Research Equipment, Inc.
Unit	4000 Trackpoint
System	Ultrashort Baseline
Output	PPI displays slant range and bearing to target
Range	Up to 5 miles
Bearing Accuracy	5° (beyond 5° from vertical)
Cost	$18.K

Manufacturer	Simrad
Unit	HPR
Full scale ranges	25 to 5000 m (8 scales)
Range resolution	0.5% of full scale
Output	PPI CRT
Accuracy	1% of water depth for 25° beam
	2% of " " " 60° beam
	5% of " " " 90° beam
Frequency	
Transponder	24 kHz
Receiver	30 kHz
Pulse length	10 ms
Operating depth	1000 m
Transducer beamwidth - conical	25°, 60°, or 160°
Transponder beamwidth	Omnidirectional
Cost	$60-70K

Manufacturer	Sonatech
Unit	400 Transceiver
	410 Transponder
Maximum ranges	5 nmi (shallow)
	10 nmi (deep)
Frequencies - transmitter 9 &	11 kHz
Pulse width	10 ms (780 command codes)
receiver	7.5 to 14.5 kHz (steps of 0.5kHz with external magnetic control)
Output	4 digital range displays (consecutive)
Transponders	Up to 8 (consecutive)
Cost	$21.3K (+ $7.5K for each transponder)

Manufacturer	Telstar
Unit	Beacons, receivers and directional hydrophones only
Activation	Sea water
Output	CW, pulse, or pinger
Depth	Up to 20,000 ft
Maximum range	Over one mile

Cost

Beacons	\$0.2 - 0-.9K
NBR 100 receiver	\$0.9K
DH Directional Hydrophones	\$0.2 - 0.3K

Category I-2 ACOUSTIC NAVIGATION

Manufacturer	Ametek/Straza Division
Unit	2017/3017B
System	Doppler Navigation
Frequency	300 kHz pulse
Transducers	4 in array
Output Display	Digital
Bottom track operation	12 ft - 600 ft depth
Watertrack operation	Beyond 600 ft depth

Speed of sound compensation by thermistors

Transducers unstabilized - up to $\pm$ 5° pitch and roll compensated by transducer intercomparison

Ship speed range	0.40 kts
Distance range	0-1000 n-mi
Ship speed accuracy	
Bottom track	0.2%
Watertrack	0.2% re water mass
	(both $\pm$ .01 n-mi/hr)
Positional accuracy	0.2% of distance
Cost	$47.K

Manufacturer	EDO Western
Unit	502
System	Doppler
Range	5 ft. to 400 ft. above bottom
Frequency	310 kHz pulse
Transducer	4 in array
Beamwidth	5°
Speed Range	-5 to +10 knots
Speed Accuracy	± 0.15% (excluding possible pitch, roll, heave and heading reference error)
Outputs	3 pulse trains with frequency proportional to fore-aft, port-starboard, and up-down velocities
Sound Speed Correction	Incorporated "velocimeter"
Cost	$35.K

Manufacturer	Electrospace
Unit	Navace - 1 Mod 87N -1
System	Contour and Sub-bottom matching (pre surveyed, geophysical signature correlation)
Supporting Sensors	narrow beam fathometer bathymetric sonar doppler sonar
Positional Accuracy	50% of grid resolution
Grid resolution	typical 6 to 15m spacing
Grid size	depends on grid resolution, accuracy desired, memory available (max. 60 km x 60 km with 60m grid resolution)
Cost	$120 K (+ sensors)

Manufacturer	GE
Unit	QUO VADIS
System	Correlation Sonar Velocity Log
Claimed accuracy	0.02 knots up to 10 knots, plus 0.2% above 10 knots
Cost	Proposal (See company for details)

Category I-3 ACOUSTIC RELEASES

Although release transponders may be utilized in the Acoustic Positioning Category I-1, this Acoustic Release Category I-3 is devoted to the releases themselves.

Manufacturer	EG&G/Sea Link
Unit	722A/723A
System	Recockable Release/Transponders
Operating depth	722A - 900m
	723A - 6000m
Release load	1100 kg, externally recockable
Command Frequency	9.3 - 10.7 kHz
Command Codes	70 via 4 digit thumbwheel switch
Activation	Mechanical cock electronically activated
Release Confirmation	Pinger rate altered from 0.5 pps to 1 pps
Battery Life	24 months
Recocking	external cocking
Cost	$7.9K and $8.3K
	(+ $7.1K for shipboard unit)

Manufacturer	ENDECO
Unit	Type 900
System	Rearmable Acoustic Release (only)
Maximum depth	300 m
Actuator load	450 kg
Range	1 nm
Command Codes	15 selectable binary codes (20 ms pulse, 0.5 pps)
Activation	high torque motor/cam
Battery life	12 months
Rearming	by external magnet
Safety feature	low-battery alarm auto release; optional timer release
Cost	$2.8K (including deck unit)

Manufacturer	ENDECO
Unit	Type 620 (NON-ACOUSTIC)
System	Deep Ocean Release Mechanism
Maximum depth	4900 m
Maximum duration	400 days
Maximum tension	4500 kg
Actuator	Clock timer (1 hr.intervals) and chemically charged piston
Cost	$3.6K

Manufacturer	Helle
Unit	5200
System	Release module
Range	4.8 km
Maximum load	2270 kg
Battery life	1 year
Depth	1220 m
Command Codes	8 codes @ 8 frequencies 22 - 36 kHz
Activation	mechanical release link electronically activated
Cost	$2.6K (+ $1.8K for command module)

Manufacturer	Innerspace
Unit	430/431
System	Underwater release
Range	1 mile
Depth	1000 ft.
Command Codes	16 (expandable to 80) at 22 kHz frequency
Battery life	3 months
Load capacity	400 lbs (multiplier to 2000 lbs available)
Activation	internal link fired to drop expendable shackle (low rearming cost)
Cost	$2.4K (+ $2.3K for shipboard unit)

Manufacturer	Innerspace
Unit	406S/406P
System	Digital Acoustic Release/Pinger
Slant range	3 mi
Depth capability	300 ft. (deeper optional)
Command Codes	100 digital binary codes (8 bits)
Release Verification	pinger rate changes from 1 pps to 2 pps (5 or 10 ms pulse length)
Battery life	6 months standby plus 10 releases plus 18 hours ping at 2 pps
Activation	Squib type explosive bolt
Safety feature	pressure sensitive switch to arm squib pinger reset by external magnet
Load capacity	1000 lbs (5000 lbs optional)
Cost	$4.2K / $3.9K

Manufacturer	Inter Ocean
Unit	1090/1090D
System	Acoustic Transponding Release
Transponder Interrogate frequency	12.0 kHz
Transponder Reply frequency	8.192 kHz
Command frequencies	12.5 - 14.5 kHz
Depth	1090 - 2500 m
	1090 - 8000 m
Maximum Axial load	2300 kg (4600 kg optional)
Activation	Motor driven release with command rearm function
Release Confirmation	timed pinger
Cost	$7.K / $7.4K

Manufacturer	Inter Ocean
Unit	2090/2090D
System	Acoustic Release

Essentially previously listed 1090/1090D without the transponder/pinger.

Cost	$5.8K / $6.3K

Manufacturer	Mesotech
Unit	501 AR
System	Acoustic Release Transponder
Receive frequency	15.625, 16.667 kHz
Transmit frequency	17.857 to 20.000 kHz (4 available)
Release codes	32
Battery life	12 months standby or 1000,000 interrogations
Operating depth	3000 ft
Release load	5000 lbs
Activation	Release motor
	(Screwdriver-resettable externally)
Release verification	2 pps pinger
Cost	Not available

Manufacturer	Sonatech
Unit	410
System	Acoustic Recoverable Transponder
Transponder Interrogate frequency	9.0 and 11.0 kHz (selectable by external magnet)
Command Codes	780
Maximum load	182 kg (907 kg and 4536 kg optional)
Life	30 months or 300 k to 1 M replies (dependent on power output setting)
Depth	3658 m (6096 m optional)
Release Verification	Signals during execution
Activation	electrolytic release mechanism (dissolving inert wire by forced anodic action) rearmed without opening housing
Cost	$7.5K

5.1.10 Category J ACOUSTIC COMMUNICATION

Manufacturer	Ametek/Straza
Unit	ATM-504A
System	Acoustic Underwater Telephone
Carrier frequency	8.087 kHz $\pm$ 1 Hz (upper sideband)
Receiver frequency response	8.087 - 11.087 kHz ($\pm$ 3dB)
Operating range	20 kyd (optimum conditions)

AN/UQC compatible

Conical and Omnidirectional beam transducers

Transmitter output	200 w
Receiver sensitivity	3 μV

Cost	$10.K

Manufacturer	GE
Unit	MATCOM
System	Proposal
Cost	See company for details

Manufacturer	Helle
Unit	3117/3118
Carrier frequency	42 kHz (AM modulation)
Battery life	3117 - 8 hrs. 3118 - 80 hrs. (both assume 10% transmission time)
Operating range	
quiet bays	1/4 mi.
quiet ocean	1/2 mi.
Acoustic power output	1/2 w
Cost	Diver unit - $0.6K Surface unit - $0.5K

Manufacturer	Mesotech/T. Thompson Ltd.
Unit	703 A
System	dual channel underwater telephone
Operating frequencies	8.0875 kHz (UQC)
	25 kHz
	(upper sideband suppressed carrier)
Transmitter output	20 w
Receive sensitivity	10 μv
Cost	$3.K

NOSC

SUBSEA SAT

Slow Scan Acoustic Television

See NOSC Technical Report No. 217

A. Gordon, FY 77 Subsea Slow-scan Acoustic Television (SUBSAT) Tests

March 1978

Manufacturer	Sound Wave Systems
Unit	Wet Phone
Carrier frequency	31.5 kHz
	(amplitude modulation)
Operating range	1350 m
Battery life	6 hours
	(continuous operation)
Acoustic power out	1.5 w
Voice actuated	
Cost	Not available

5.1.11 Category K ACOUSTIC BOTTOM PROFILING

Manufacturer	EDO Western
Unit	4041
System	Stabilized Narrow Beam Bathymetric
Operating frequencies	16, 25, 35 kHz
Operating depth	500 ft.
Maximum depth range	3000-45000 fathom
Pulse lengths	1ms, 5ms, 10ms
Output power	2000 w (optional 10,000 w)
Beam widths	6.5°. 4.2°. 2.8°
Stabilized Platform	+20° each axis @ 8°/sec.
Vessel Speeds	8 - 12 kts
Time Variable gain (TVG)	40 dB gain variation in 100 ms
TVG range	60 dB
TVG rise time	2 to 100 ms
TVG delay	2 ms to 1 sec.
Cost	$122.K

Manufacturer	EDO Western
Unit	4077
System	Narrow Beam Towed Bathymetric
Water depths	10,000 ft.
Tow speeds	12 kts
Beam widths	5° and 10°
Pulse widths	1, 2, and 4 ms
Operating frequencies	24 and 40 kHz
Power output	2000 w
Heave Compensation	acceleration measurement produces reference timing signal, range $\pm$ 20 ft.
Depth sensor	pressure sensor in tow body (1% accuracy)
Output	paper recorder
Time Variable Gain	0 to 60 dB, 2 to 100 ms rise time, 2 ms to 1 sec. time delay
Cost	$30.9K

Manufacturer	EDO Western
Unit	4058
System	Altitude Sonar
Operating frequency	200 kHz
Beam width	15°
Range	0.3 to 40 m
Accuracy	0.2 m (for 1468 m/s sound speed)
Output	Serial 12 bit, 3 digit Binary Coded Decimal
Maximum Pressure	3000 psi
Time Variable Gain	Auto compensation for spreading and attenuation losses
Cost	$7.5K

Manufacturer	Electrospace
Unit	Trench Profiler
System	Modification of single channel of sidescan sonar
Proposal	(See Co. for details.)
Cost	\$35.K

Manufacturer	Innerspace
Unit	415/418
System	Height Tracker/Transceiver (automatic tracking gate)
Operating frequency	200 kHz Height tracker can also operate with a standard 12 kHz pinger
Range	250 ft. (415) 1000 ft. (418)
Pulse length	100 μs
Beam pattern	16° conical
Depth capability	3000 ft.
Output	4 digit LED display; zero center meter analog display adjustable from 10 ft. to 100 ft. full scale; audioble and visual alarms for bottom track loss, high limit, and low limit
Cost	415 - $3.3K 418 - $5.5K

Manufacturer	Innerspace
Unit	412
System	Autotrack
	(used with 418 transceiver)
Less sophisticated than Model	415
Output	digital display and BCD
Speed of sound input	manually adjustable
Cost	$3.7K

Manufacturer	Inter Ocean
Unit	1296
System	Altitude Sonar
Frequency	54 kHz
Beam width	60°
Pulse length	1 ms
Range	3 to 500 m
Range resolution	10% of range
Maximum operating depth	20,000 ft.
Output	BCD
Time Variable Gain	Yes
Cost	$30.0K

Manufacturer	Inter Ocean
Unit	2168
System	Digital Depth Sounder
Frequency	15 or 50 kHz
Beam width	30° cone
Pulse length	1 to 20 ms, variable
Accuracy	0.5 ms, independent of depth
Operating depth	7,000 m
Output	Digital travel time plus digital output
Time Variable Gain	Yes
Cost	Not available

Manufacturer	International Submarine Technology, Ltd.
Unit	Altimeter
Frequency	260 kHz
Beam width	20° (5° available)
Pulse length	Automatic variable .075 ms - .150 ms
Full scale ranges	4, 20, 80 m
Resolution	0.05% of full scale
Sound speed correction	man. adjustable
Time Variable Gain	automatic, 60 dB range
Output	TV analog of vehicle altitude, ascent//descent rate, and bottom character
Cost	$10.K

Manufacturer	Mesotech Systems, Ltd.
Unit	952
System	Bottom Scan Profiling Sonar

(Profiles across track along several lines of bearing - locked for precision depth sounder)

Hull mounted

Frequency	360 kHz
Beam width	1.5°
Full scale ranges	20, 40, 80, 160 m
Range accuracy	±0.5% of full scale
Sweep angles	
(from vertical	±22.5°, ±45°, ±67.5°, ±90°
Inclinometer to sense rolling	
Output	CRT and Plotter
Cost	\$37 - \$44K

Manufacturer	Mesotech Systems, Ltd.
Unit	961
System	Bottom Scan Profiling Sonar

(Scans across track along several lines of bearing)

Hull mounted

Operating Frequency	360 kHz
Beam width	1.5°
Full scale ranges	10, 20, 40 m
Range accuracy	±0.5% of full scale
Output	CRT and Plotter
Cost	$37 - $44K

Manufacturer	O.R.E. (Ocean Research Equipment)
Unit	261/263
System	Pinger, standard and high power
Beam pattern	261 hemispherical
	263 35°
Frequency	12 kHz
Pulse length	0.5, 2, 4, 10 ms
Repitition Rate	1 pps (upright)
	2 pps (inverted)
Maximum depth	9500 m
Battery life	100 hours at minimum pulse length
Cost	\$3.4K / \$3.8K

Manufacturer	Raytheon
Unit	DSF-600
System	Digital Survey Fathometer (Used in Teledyne Geotech Model HSS-100D Automated Hydrographic Surveying System)
Operating Frequency	200 kHz
Beam width	20°
Power	400 w
Recording Accuracy	7.6 cm up to 30 m depth, 0.25% of indicated depth up to 600 m depth
Output	BCD digital display, and chart recorder
Cost	$23.4K

Manufacturer	Simrad	
Unit	EA	
System	Hydrograpnic Echosounder	
Range	0.25 - 1700 m	
Frequency	38 kHz	710 kHz
Power with transducer	500 watts	25 watts
Pulse length	0.3 (1.3) ms	0.05 ms
Beam width (min.)	7° x 7°	
Output	digital depth and BCD and paper chart	
Resolution	0.1 m from 0 to 199.9 m depth 1 m from 200 to 1700 m depth (Calibrated to set sound speed and transducer depth)	
Cost	$16.K	

Manufacturer	UDI/Highlands
Unit	AS-1000 A
System	Seabed (Trench) Profiler
Operating frequency	200 kHz
Beam width	2°
Maximum altitude	30.5 m
Maximum depth	213.5 m
Depth accuracy	0.1%
Profiler accuracy	< 101.6 mm
Heave compensation range	30.5 m
Cost	$52 K (combined with Sub-bottom)

5.1.12 Category L ACOUSTIC SUB-BOTTOM PROFILING

Manufacturer	EDO Western
Unit	515 A*
System	Hi Pact Bottom Penetration
Operating frequency	0.7 - 2.25 kHz
Beam width	73°
Pulse length	0.6 - 200 ms
Penetration	136 - 1500 ft.
Resolution	3 - 5 ft.
Output	Chart recorder
Heave compensation range	$\pm$ 10 ft.
Vehicle depth	200 ft. (1000 ft. optional)
Maximum speed	12.5 kts
Cost	$23.K (hull mounted)
	$34.K (towed version)

*Three different versions are marketed.

Manufacturer	EDO Western
Unit	515 A*
System	Hi Pact Bottom Penetration
Operating frequency	(a) 1.25 - 3.75 kHz
	(b) 2.0 - 5.0 kHz
Beam width	(a) 45°
	(b) 35°
Pulse length	0.5 ms - 200 ms
Penetration	(a) 90 - 980 ft.
	(b) 72 - 730 ft.
Resolution	(a) 2 - 3 ft.
	(b) 1.5 - 2.2 ft.
Output	Chart recorder
Heave compensation range	$\pm$ 10 ft.
Vehicle depth	200 ft. (1000 ft. optional)
Maximum speed	12.5 kts
Cost	$23.K - $34.K

*Three different versions are marketed.

Manufacturer	EDO Western
Unit	515 A*
System	Hi Pact Bottom Penetration
Operating frequency	(a) 2.0 - 5.0 kHz
	(b) 4.0 - 10.0 kHz
Beam width	(a) 45°
	(b) 27°
Pulse length	0.2 ms - 200 ms
Penetration	(a) 72 - 780 ft.
	(b) 45 - 520 ft.
Resolution	(a) 1.5 - 2.2 ft.
	(b) 0.8 - 1.2 ft.
Output	Chart recorder
Heave compensation range	± 10 ft.
Vehicle depth	200 ft. (1000 ft. optional)
Maximum speed	12.5 kts
Cost	$23.K - $34.K

*Three different versions are marketed.

Manufacturer	EG&G Environmental
Unit	230
System	Uniboom
Tow depth	Surface
Water depth	300 m
Tow speed	5.5 kts
Sound source	Single broad band acoustic pulse
Frequency range	0.40 to 14 kHz
Pulse length	< 0.2 ms
Bottom penetration	40 m - 50 m
Resolution	15 cm
Output	Chart recorder
Cost	$30.K

Manufacturer	EG&G Environmental
Unit	240
System	Uniboom Subtow (all-weather)
Tow depth	0 - 15 m
Water depth	> 15 m
Tow speed	10 kts
Sound source	Single broad band acoustic pulse from magnetically repelled plate
Frequency range	1 kHz - 8 kHz
Pulse length	< 0.2 ms
Bottom penetration	60 m - 90 m
Resolution	15 cm
Output	Chart recorder
Cost	$43.3K

Manufacturer	EG&G Environmental
Unit	Sparkarray
System	1kJ, 8kJ
Tow depth	0 - 15 m
Water depth	> 15 m
Tow speed	12 kts
Sound source	electrical discharge-generated bubble
Frequency range	0.1 - 1 kHz, 0.04 - 0.4 kHz
Pulse length	4 ms, 11 ms
Bottom penetration	150 m, 1200 m
Resolution	3 m, 5 m
Output	Chart recorder
Cost	$29.5K, $45.4K

Manufacturer	Electrospace
Unit	Star Pro
System	Sub Bottom Profiler
Operating power	10 kw or 2 kw
Operating frequency	3.5 to 7 kHz standard
Pulse width	1, 2, 4, 8 ms standard
Output	Chart recorder
Time Variable Gain	selectable delay, initial and final gain, and slope
Cost	$50.K

Manufacturer	Fairfield
Unit	Fairflex
Tow depth	0.5 m
Frequency	0.05 to 1 kHz
Pulse length	3 ms
Sound source	oxygen-propane detonation in rubber sleeves

Twelve trace streamer towed at 3 m depth

Single trace ministreamer towed at 1.5 m depth

Penetration	> 700 ft.
Cost	$130.K

Manufacturer	Fairfield
Unit	SS75
System	Radial Supersparker
(Used with streamer hydrophones)	
Output power	15.4 kJ
Frequency spectrum	40 - 500 Hz
Pulse length	10 ms
Towing depth	10 - 12 ft.
Penetration	5000 ft.
Resolution	25 ft.
Transducer	ten spark-electrode gaps
Cost	$10.K

Manufacturer	Huntec ('70)
Unit	DTS
System	Deep Tow Seismic
Water depths	to 2000 m
Tow depth	0 - 300 m
Tow speed	10 kts
Layer resolution	0.2 m
Penetration	> 200 m
Transducer	"boomer" driven plate
Pulse length	120 μs

Body Motion Compensation adjusts system triggering

Adaptive Signal Processing	corrects for attentuation, reflectivity, and divergence losses
Cost	$108.K

Manufacturer	Innerspace
Unit	201/202/203
System	Sparker, Preamp/Filter/Streamer (Small boat system)
Output power	25 Joules (into electrodes)
Penetration	60 ft. sediment
Cost	$13.K

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FORECAST OF REMOTE UNDERWATER SENSING TECHNOLOGY.(U)

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Manufacturer	Inter Ocean
Unit	3000
System	Sub-bottom profiling (shallow water surveys)
Output power	1 kw
Frequency	6.4 kHz
Pulse length	0.2, 0.5, 1, 2, 5 ms
Beam width	35°
Battery life	10 hours
Output	paper chart
Time Variable Gain	Yes
Price	Not available

Manufacturer	Klein
Unit	532S
System	Sub Bottom Profiler
Output frequency	3.5 kHz
Pulse length	0.4 ms
Beam width	50° conical
Depth rating	300 m (12,000 m optional)
Resolution	60 cm in water
Cost	$29.K

Manufacturer	Lister
Unit	Mk III
System	Bubble Pulser only
Frequency	500 Hz nominal (peak)
Pulse length	4 ms
Transducer	electromagnetic
Stored energy	16 Joules
Tow depth	surface
Cost	$8.K

Manufacturer	UDI/Highlands
Unit	AS 1000
System	Sub-bottom profiler
Frequency	4 kHz
Acoustic power	5 kw
Beam pattern	45° x 60°
Depth	213.5 m
Heave compensator range	30.5 m
Cost	$52.K (combined with profiler)

5.1.13 Category M ACOUSTIC ENVIRONMENTAL

Manufacturer	Grundy
Unit	4031/4310
System	Sound Speed Sensor
Measurement Range	1400 - 1600 m/s
Accuracy	$\pm$ 0.15 m/s
Resolution	0.0004 m/s
Time Constant	70 u sec
Depth rating	4031 20,000 ft.
	4310 1,800 ft.
Cost	4031 $5.4K
	4310 $3.0K

Manufacturer	Ametek Straza
System	Doppler Sonar Ocean Current Profiler
Ship speed range	15 kts
Water track depth	2 - 500 ft.
Velocity profile depth resolution	10, 20, 40 ft.
Velocity accuracy	$\pm$ 0.5% + .02 kts
Data output	analog plus 16 bit parallel digital
Cost	$32.K

Manufacturer	Neil Brown
Unit	ACM-2
System	Acoustic Current Meter
Range	0 to ± 250 cm/s
Vector magnitude accuracy	± 1 cm/s or 5%
Linearity	± 1%
Cosine response	± 2%
Response time	0.2 sec.
Vector direction accuracy	± 5°
(for mag. greater than 10 cm/s	
Data output	digital tape
Cost	$12.K - $15.K

Manufacturer	Inter Ocean
Unit	691-9
System	Sound Speed
Range	1400 - 1600 m/s
Resolution	0.001 m/s
Stability	short term - 0.005 m/s
	6 months - 0.02 m/s
Calibration accuracy	160 μs
Maximum depth	1000 m (3000 m, 6000 m optional)
Cost	$13.3K

Manufacturer	Simrad
Unit	CMI
System	Ultrasonic Current Meter
Range	0 - $\pm$ 2.5 m/s
Resolution	1mm/s
Accuracy	$\pm$ 3% full scale
Sampling rate	30 per sec.
Maximum depth	1000 m
Data output	digital cassette
Cost	$3.K

Manufacturer	Sippican
Unit	XSV
System	Expendable Sound Velocimeter
Sound speed accuracy	± .25 m/s
Depth	0 - 850 m
Depth accuracy	± 2% or 5m
Ship's speed	0 - 15 [illegible]s
Cost	$66.00

5.2 OPTICS

5.2.1 Category N. OPTICAL DETECTION/LIDAR

There are no systems commercially available at present. Work is underway on laser bathymetry through NORDA and on laser hydrofoil obstacle detection through NOSC.

5.2.2 Category O. OPTICAL IMAGING - AREAL

Except for limited range or daylight illuminated optical imaging, there are no systems commercially available. Systems used for search, especially, have been developed by the users. These include WHOI, NORDA, NUSC, NOSC, and NRL. The following list is principally limited to the optical detectors used for areal imaging.

Manufacturer	Benthos
Unit	371, 372, 377
System	Film cameras only
	(Utility, Standard, and Survey)
Format	35 mm
Lens - focus	0.6 m - ∞
focal length	35 mm in water (medium wide angle)
Exposures	80, 800, 3200
Depth rating	12,000 m
Data systems	Optional
(Flash units from 50 to 1500 watt-seconds)	
Cost	\$5.2K, \$7.9K. \$14.1K

Manufacturer	EDO Western
Unit	1641
System	Television Camera Only
Resolution	800 horizontal TV lines
Sensitivity	0.1 foot-candle faceplate
Lens	12.5mm, f/1.4, water corrected
	63° horizontal angle of view
Focus	Camera face to infinity, remote controlled
Pressure rating	2500 psi

(150 w Thallium Iodide Light available)

Cost	$13.6K

Manufacturer	Hydroproducts
Unit	TC-125
System	Modular TV
Lens	12.5 mm, f/1.4, 46° in water
Focus	3 in. to infinity, remote controlled
Resolution	600 horizontal TV lines minimum
Sensitivity	1.0 foot-candle yields 600 TV lines
	0.1 foot-candle yields 400 TV lines
Target control	10,000:1 automatic
Depth rating	2,000 ft (20,000 ft optional)
Cost	$3.9K

Manufacturer	Hydroproducts
Unit	TC-125-SIT
System	Low light level TV
Lens	12.5 mm, f/1.4. 46° in water
Sensitivity	0.0005 foot-candle yields 300 TV lines
	0.001 foot-candle yields 400 TV lines
Target control	Five million to 1
Depth rating	2,000 ft (20,000 ft. optional)
Cost	$19.0K

Manufacturer	Profiline
Unit	CC22
System	Color TV
Resolution	270 lines in center
Lens	Angle 130° in water
Focus	3 cm to ∞
Scanning	625 lines 50 Hz
Depth rating	300 m (100 m cable to topside unit)
Cost	DM45.K (including searchlight and console)

Manufacturer	Rebikoff
Unit	DR 633
System	Color TV
Lens	f/1.8
	7.5 mm
	100° angle in water

(Always in focus)

Resolution	270 lines horizontal

1 in. tri-electrode single vidicon tube

Depth rating	200 m (500 m and 2000 m optional)
Cost	$22.K

Manufacturer	Rebikoff
Unit	DR 8250
System	35 mm film camera
Lens	T/3.4
	21 mm
	92° angle in water

(Always in focus)

250 exposure magazine

Battery	6 standard C alkaline cells

Red flash and beeper leak warning system

Cost	$15.K

Manufacturer	Rebikoff
Unit	DR 646
System	Low Light Level TV
Lens	f/1.4
	6.5 mm
	105° angle in water

(Always in focus)

Resolution	600 lines capability

(Fully automatic camera without controls)

Depth rating	200 m (500 m and 2000 m optional)
Cost	$12.K

Manufacturer	Remote Ocean System, Inc.
Unit	XL 6000
System	Film Photography and Motion Pictures
Lens	8.5 mm to 24 mm focal length available
	34° in water angle (with 8.5 mm focal length)
Cartridge	Super 8 w/3600 exposures (ASA 160 Type G Ektachrome)
	Automatic exposure control
Batteries	4 siz AA 1.5 volt alkaline
Operating depth	6,000 ft.
Cost	$1.4K

Manufacturer	Sub Sea Systems
Unit	SL-75/85
System	SIT and ISIT TV (low light level)
Light range	Full daylight to cloudy moonlit (SIT) to cloudy moonless (ISIT) (in air). (Fully automatic operation)
Size	2.15 in diameter x 22 1/2 inches long
Cost	SIT $17.1K ISIT $21.5K

Manufacturer	Video Sciences, Inc.
Unit	Explorer II
System	Diver TV
Lens	f/1.5, 8.5 mm, domed-port, 63° field of view (f/1.8, 4.8 mm, 110° field of view available)
Tube	2/3 inch vidicon
Resolution	550 lines horizontal center minimum
Operational depth	350 ft.
Umbilical	200 ft (2000 ft available)
Cost	$13.9K (Including 9" diag. monitor and video cassette recorder)

5.2.3 Category P. OPTICAL IMAGING-RANGE GATING

There is no commercially available system for optical range-gated imaging underwater. However, the Naval Research Laboratory has partially tested (in air) a system called SEGAIP (Self Gated In-Water Photography). Calculations made for this intensified camera/laser system predict 2 mr resolution at 80 m ranges with a 64° FOV lens. Photographs are made 4 times per minute.

5.2.4 Category Q. OPTICAL IMAGING - SCANNING

No underwater optical imaging systems utilizing object scanning are commercially available. However, an early fan scan system was developed by Tetra Tech, Inc. This was followed by the dual-scan system LOOK-SEA developed at NUSC under ARPA auspices. NOSC later proposed their own towed version of fan-scan operating much like an optical analog of side-looking sonar. NOSC partially demonstrated a strip scanning search system ROMS (Real-Time Optical Mapping System).

5.2.5 Category R. OPTICAL COMMUNICATION

The only activity in this technology is apparently the classified air to submarine optical communication.

5.2.6 Category S. OPTICAL ENVIRONMENTAL

Manufacturer DISA Electronics

(Project of the Department of Physical Oceanography of the University of Copenhagen)

Unit LDA Oceanography (Laser Doppler Anemometry)

System Measurement of fine structure of ocean and river currents

Manufacturer	ENDECO
Unit	815
System	V-FIN Fluorometer

(Uses Turner Designs Mod. 10-0 Fluorimeter)

Sensitivity	10 parts per trillion Rhodamine B
	5 parts per trillion chlorophyll "A"
Precision	Linear to ± 1%, readable to ± 1/2
Operating Depth	200 m
Towing speed	12.5 knots
Response time	1 sec to 63% full scale
	4 sec to 98% full scale
Cost	$22.5K

Manufacturer	ENDECO
Unit	925
System	Petro-Track

(Uses Turner Designs Mod. 10-U Fluorimeter)

Sensitivity	5 ppb oil in water
Precision	Linear to ± 1%
	Readable to ± 1/2%
Response time	1 sec to 63% full scale
	4 sec to 98% full scale
Depth range	0 to 100 m
Cost	$47.6K

Manufacturer	GE
Unit	VAS
System	Virtual Acoustic Sensor

Optical heterodyne doppler system

Senses steady flow and acoustic vibrations of natural particles in water

Cost	Proposal (see Company for details)

Manufacturer	Impulsphysics
Unit	Variosens F/Variosens OS
System	Fluorometer
(Measures plankton content to 0.1 ppb)	
Sensitivity	2 X 10^{-11} for Rhodamine
("OS" measures oil from 10^{-9} to 10^{-5})	
Response time	1 decade in 1/3 sec
Measuring range	4 decades
Tow speed	12 kts
Depth rating	800 m (3000 m optional)
(Capable of operating in surf zone)	
Cost	$15.9K

Manufacturer	International Light
Unit	IL700
System	Research Radiometer
	Digital display
	Programmable readout (any units)
	Integration mode for pulsed sources

Head specifications (SEA-010):

Response	450 to 950 nm ($\pm$ 7%)
Minimum detectable signal	1×10^{-11} w/cm^2
Linearity	$\pm$ 1%
Cosine response	$\pm$ 2° (with barrel)
Cost	\$1.3K (plus 0.2K - 0.4K for head)

Manufacturer	Kahlisco
Unit	269WA170
System	Turbidity Meter
Path length	1 m (adjustable)
Depth rating	100 m
Output	% transmittance
Cost	$6.3K

Manufacturer	Kahlisco
Unit	268WA310
System	Irradiometer

(Measures incident, attenuated, or reflected solar or lunar energy)

	6 decades of range
Output	Radiometric or photometric
	digital or analog display
Operating depth	Up to 300 m
Cost	$1.7K

Manufacturer	Turner Designs
Unit	10-U
System	Field fluorometer
Sensitivity	10 parts per trillion Rhodamine B
	5 parts per trillion Chlorophyll A
Precision	Linear to ± 1%
	Readable to ± 1/2% full scale
Response time	1 sec to 63% full scale
	4 sec to 93% full scale
(X 10 speed with 3X loss in sensitivity optional)	
Operating depth	200 m
Cost	$5.0K

5.3 Category T. MAGNETIC

Manufacturer	Barringer
Unit	SM-123
System	Shallow Marine Magnetometer (Proton precession)
Sensitivity	1 gamma
Accuracy	± 1 gamma
Range	20k to 100 k gammas
Output	Analog or digital or BCD
Depth capability	500 ft
Cost	$11.5K

Manufacturer	Barringer
Unit	DM-123
System	Oceanographic Magnetometer (proton precession)
Sensitivity	1 gamma
Accuracy	$\pm$ 1 gamma
Range	20k to 100 k gammas
Depth	"Unlimited" (750 ft tow cable standard)
Output	Analog, digital, BCD
Cost	$19.6K

Manufacturer	Electrospace
Unit	Flux gate Sensor
System	ESI Pipe Tracking (Proposal)

SEE COMPANY FOR DETAILS

Manufacturer	EG&G Geometric
Unit	G-801G
System	Marine Proton Gradiometer
Sensitivity	0.125 gamma; 0.00025 gamma/foot
Accuracy	± 0.5 gamma
Range	20k to 100k gammas
(10k to 15k without retuning)	
Tow cable	Single cable with sensor at 750 ft and at 1250 ft
Output	Analog, digital and BCD
Cost	$65.K

Manufacturer	EG&G Geometric
Unit	G-806M
System	Marine Search Proton Magnetometer
Sensitivity	0.5 gamma @ 10 sec sampling
	1 gamma @ 1 sec sampling
Accuracy	± 1 gamma
Range	20k to 100k gammas
Tow cable	200 ft
Output	Chart, digital and BCD
Cost	$15.5K

Manufacturer	Varian of Canada
Unit	V-75
System	Marine Magnetometer (proton)
Range	20k to 100k gammas
Sensitivity	± 0.1 gamma
Accuracy	± 1 ppm
Towing cable	500, 750, 1000 ft lengths
Outputs	Analog, digital and BCD
Cost	Not available

Manufacturer	Digicourse
Unit	309
System	Underwater Heading Sensor
Compass Repeatability	$\pm$ 1/2°
Resolution	1°
Depth Capability	300 ft.
	$\pm$70° roll and pitch
Transmit Range	2000 ft. (35,000 ft. optional)
Output	Serial pulse train.
Cost	$1.0K

Manufacturer	Digicourse
Unit	320
System	Heading Sensor
Repeatability	$\pm$ 0.5°
Resolution	1.0°
Pressure Rating	10,000 psi
Gimballing	360° continuous roll
	$\pm$60° pitch
Transmit Range	35,000 ft.
Output	9-bit binary word
	(enables multiplexing of 100 sensors)
Cost	$8.0K

5.4 Category U. ELECTRIC FIELD

Manufacturer	Technology Development Corp.
Unit	Hydrocom
System	Underwater Electric Field Communication (Divers)
Range	300 ft
Depth rating	300 ft
Cost	

5.5 Category V. ELECTROMAGNETIC/ENVIRONMENTAL

Manufacturer	GOULD/CID
Unit	UL-100-3
System	Electromagnetic Underwater Speed Log
Speed Range	-9 to +70 kts
Distance Range	0 to 9,999.99 n-mi
Speed Accuracy	± 0.1 knots to 10 knots
	±1% above 10 knots
Distance Accuracy	±0.1% of travel
Output: speed	3 digit LED and 12 bit binary
distance	6 digit counter with 100 contact closures/n-mi
Cost	$11.8K

Manufacturer	Aanderaa
Unit	TR 1
System	Temperature Profile Recorder
Accuracy	± 0.15°C
Resolution	0.1% of range
Sensors	11 Thermistors
Depth Capability	2000 m
Standard length	20 m
Measuring speed	4 seconds each channel
Response time	3.5 minutes for 63% of full scale
Sampling intervals	0.5-180 min.
Telemetry	Acoustic @ 16 k Hz with range typically 800 m or by cable.
Cost	$3.5K

Manufacturer	Beckman
Unit	RS5-3
System	In-situ Salinometer
Salinity Range	0-40 ppt ± 0.3 ppt
Temperature Range	0-40°C ±0.5°C
Depth Range	400 ft.
Accuracy	(Using error curves)
Salinity	±0.05 ppt
Temperature	±0.05°C
Cost	$1.3K (plus cable)

Manufacturer	Neil Brown Instrument Systems. Inc.
Unit	Mark III
System	CTD
Pressure Ranges	0-6500 decibars
Pressure Accuracy	0.1% full scale (0.05% optional)
Temperature Range	-32°C to +32°C
Temperature Accuracy	0.005°C
Conductivity Range	1 to 65 mmhos
Conductivity Accuracy	0.005 mmhos
Scan Time	32 ms
Sensor Response Time	30 ms
Spatial Resolution	1 cm
Measurement Resolution	.0015% full scale
Depth Capability	6500 m
Output	Digital Display plus output

(zero drift eliminated by AC technique)

Cost	$28.K

Manufacturer	ENDECO
Unit	741
System	Deep Water Tethered Current Meter
Sensitivity	50 rpm/Kt
Speed	0-5 kts
Resolution	0.4% of speed range
Accuracy	±3% of full scale
Current Direction	0-360°
Direction Resolution	1.4°
Direction Accuracy	±7.2° above 0.05 kts
Output	Digital magnetic tape recording
Cost	$9.1K

Manufacturer	ENDECO
Unit	109
System	Thermograph
Temperature Range	-2°C to +32°C
Accuracy	±0.2°C
Resolution	±0.1°C
Recording Rate	1 reading every 15 or 30 or 60 maximum
Maximum Depth	150 m (6100 m optional)
Output	Analog bar-graph of mercury column position on film
Cost	$1.6K

Manufacturer	ENDECO
Unit	101
System	Recording Salinometer
Salinity Range	0-45 ppt
Salinity Accuracy	$\pm$0.2 ppt
Temperature Range	-2°C to +35°C
Temperature Accuracy	$\pm$ 0.2°C
Maximum depth	60m
Data Sampling	1 per hour
Service period	45 days
Output	16 mm film magazine

(refractometer is brushed clean prior to each reading)

Cost	$6.9K

Manufacturer	Grundy
Unit	9051
System	Telemetry Ocean Profiling
Salinity range	30-40 ppt
resolution	0.0003 ppt
accuracy	$\pm$ 0.02 ppt
time constant	0.350 sec
Temperature range	-2°C to 35°C
resolution	0.001°C
accuracy	$\pm$ 0.02°C
time constant	0.350 sec
Depth range	0.to 1500 (3000, 6000 m optional)
resolution	0.0006% full scale
accuracy	$\pm$ 0.1% full scale
time constant	0.02 sec
Outputs	16 bit binary or 21 bit BCD
Cost	$35.4K

Manufacturer	Inter Ocean
Unit	5000
System	In Situ Monitor STD
Salinity Range	0-45 ppt
Precision	±0.02 ppt
Time constant	1.4 sec (100 ms optional)
Temperature range	-5°C to +45°C
Precision	±0.02°C
Time Constant	1.4 sec. (60 ms optional)
Depth Range	0 to 100 m or 6000 m
Precision	±0.15% FS
Time Constant	60 ms
Output	Digital display, analog and digital BCD output
Cost	$13.K

Manufacturer		Inter Ocean
Unit		660D
System		High Precision Deep Water CTD
Conductivity:	Range	0-65 mmhos/cm
	Precision	± 0.005
	Time Constant	20 ms
Temperature:	Range	-5°C to 35°C
	Precision	+0.005
	Time Constant	60 ms
Depth:	Range	0-1000, 3000, 6000 m
	Precision	$\pm 0.2\%$
	Time Constant	25 ms
Output		Parallel analog (digital option)
Cost		$2.5K

Manufacturer	Lister
Unit	Pogoprobe
System	Digital Telemetering
	Heat Flow
Variable bottom penetration	
Bridge sensitivity	0.001°C over 10°C range
Output	Acoustic FM telemetry to recorder display
Battery Life	30 hours
Cost	$27.K

Manufacturer	Marinco
Unit	B-10
System	Bidirectional Ducted Current Meter
Range	0-5 Kts
Accuracy	$\pm$ 3%
Sensitivity	0.05 kt
Output	16 pps/kt
)eoth	2000 ft.
ɔst	\$0.7K (plus readout)

Manufacturer	Marinco
Unit	Q-9
System	Geomagnetic Savonius
	Rotor Current Meter
Speed range	0-7 kts
Speed Accuracy	$\pm$0.05 kt above 0.1 kt
Direction Accuracy	$\pm 5°$
Speed Threshold	0.05 kt
Direction Threshold	0.05 kt
Depth	full ocean
Maximum Tilt angle	$\pm 20°$
Cost	$2.4K (Plus readout)

Manufacturer	Marsh McBirney
Unit	585
System	Adaptive Recording Current Meter
X&Y Components of velocity relative to case	
Range	±10 ft/sec
Accuracy	±2% ±0.07 ft/sec
Resolution	0.005 ft/sec
Orientation of case relative to magnetic north	
Range	0 to 360°
Accuracy	±2°
Resolution	1.406° (8 bits)
Pressure to 300 psia optional	
Output	Digital recording tape
Cost	$9.5K

Manufacturer	Marsh McBirney
Unit	555B
System	Current Monitor
Ranges	0 to $\pm$ 2, $\pm$5, $\pm$10 ft/sec
Resolution	0.03 ft/sec /$\surd$ T
	(T is output time constant)
Accuracy	$\pm$2%
Zero Drift (long term)	$\pm$0.07 ft/sec
(Geomagnetic compass included)	
Depth raging	6000 ft.
Cost	$7.0K

Manufacturer	Sea Bird
Unit	SBE - 4 - 02
System	Conductivity Meter
Accuracy	0.003 mmho/cm typ.
Resolution	5×10^{-4} mmho/cm at 12 samples/sec 1×10^{-4} mmho/cm at 3 samples/sec
Response Time	.170 ms@ 4 knots tow speed
Pressure Capability	5000psi (10,000 psi optional)
Output	0.7 V rms Sine wave 7 to 11 kHz for 20 to 50 mmho/cm
Cost	$1.4K

Manufacturer	Sea Bird
Unit	SBE-3-02
System	Oceanographic Thermometer
Accuracy	±0.003°C/6mos. typical
Resolution	0.0005° C @12 samples/sec.
	0.0001°C @ 3 samples/sec
Response Time	70 ms @ 1m/s tow
Output	0.7 V rms sine wave
	7 to 11 kHz for 0-25°C
Depth Capability	5000 psi (10,000 psi optional)
Cost	$1.K

5.6 OTHER ACOUSTICS

5.6.1 Category W. ACOUSTIC BUOYS/ SONOBUOYS

Sonobuoys in current production are apparently all designed for military application. Therefore, no representative systems are detailed in this section Companies active in this field include: Bunker Ramo Corporation, Electronic Systems Division; General Electric Corporation; Lockheed-California Company; Sanders, Ocean-Systems Division; and Sparton Corporation, Sparton Electronics Division. The last is probably the largest supplier.

5.6.2 Category X. ACOUSTIC ARRAYS

The most sophisticated acoustic arrays are those designed and constructed for the military. This section details a few of the strictly civilian arrays. Military suppliers include: Gould, Chesapeake Instruments Division; Sparton Corporation, Sparton Electronics Division; General Electric Corporation; and Western Electric Corporation.

Manufacturer	Benthos
Unit	100/200 P
System	MESH (Multi-Element Steamer Hydrophone) Array

- -4 Active Sections
- -Each Active section has 50 hydrophone cartridges connected in parallel (200 total)
- -Each Active Section is 25 ft. long (100 ft. total)
- -One isolator head section 25 ft. long
- -One isolator section (25 ft.) between each active section
- -One rope tail 100 ft. long
- AQ-1 hydrophones (cylindrical) with response ±0.5dB from 0.5Hz to 3kHz
- -tow speed 15 kts
- -depth rating 6000 ft.
- -buoyancy - slightly negative

Cost	$7.8K (plus $1.45/ft for cable)

Manufacturer	Fairfield
Unit	MMS 78
System	Minimarine Streamer
Active Length	50 m
Hydrophone Array	linear, 60-phone group, transformer coupled
Frequency Response	3dB between 7 to 1000 Hz
Pressure Rating	125 psi maximum
Tubing O.D.	3.5 cm.
Towing Speed	12 kts.

Neutrally buoyant in sea water

Cost	$102.8K for 24 trace streamer

Manufacturer	Innerspace
Unit	203
System	Hydrophone Streamer
Active Array	10 ft.
Oil filled Section	30 ft.
Total length	200 ft.
Hydrophone	20 epoxy encapsulated lead zirconate titanate cylingers
Frequency Response	flat from 50 Hz to 3 kHz
Outer Diameter	7/8 inch
Cost	$1.9K

5.6.3 Category Y. ACOUSTIC PROCESSORS / BEAMFORMERS

It has been noted that digital beamforming as a topic is a Pandora's box of complexity and variety. It is also true that the most advanced implementations are for military applications. Companies active in this field include: Western Electric Corporation; Bunker Ramo Corporation; General Electric Corporation; IBM, Federal Systems Division; and Sanders Associates, Inc.

5.7 Category Z. CHEMICAL

Manufacturer	Inter Ocean
Unit	SNIFFER
System	Hydrocarbon Seep Detection
Sampling Depth	600 Ft. cable
	towed @ 7-12° off Vertical
Sensitivity	5×10^{-9} ml gas/ml water
	(can detect plumes as far away as 20 km)
Output	Chromotogram and Histogram presentation of total hydrocarbons plus methane, ethylene, ethane, propane, iso-butane, and normal butane. Also continuous trend data of above plus STD. Contour maps are final product.
Tow speed	10 kts.
Auxiliary instrumentation	STD sensors, bottom sonar, electromagnetic current meter
Cost	$750.K

CHAPTER 6 FORECAST OF TECHNOLOGIES

This forecast portion of this report has been handled primarily in a modified Delphi manner. Primarily to minimize the effort requested of the purely voluntary participants, there was no recursion. That is, after the first round of replies to specific questions, the participants were not informed of the results and were not given an opportunity to modify their original responses.

As discussed earlier, specific questionnaires (duplicated as Appendix B herein) were prepared for nine specific categories, viz.:

- A. Acoustic-Detection-Obstacle Avoidance Sonar
- B. Acoustic-Detection-Portable (Hand Held) Sonar
- D/E. Acoustic-Imaging/Mapping-Scanning
- I. Acoustic-Positioning/Navigation
- J. Acoustic-Communication/Telemetry
- K. Acoustic-Environmental-Bottom Profiling
- L. Acoustic-Environmental-Sub bottom Profiling
- O/P/Q. Optical-Imaging
- T. Magnetic Field-Magnetometers

The format utilized in this Chapter is, after restating the question in a simplified form for brevity, to tabulate the answers in graphic form. This is done separately for 1990 A.D. and for 2005 A.D. Most of the replies were restricted to a multiple-choice selection thus simplifying the presentation of the tabulation although it is realized that this presented some constraints on the participants. Indeed it was remarked that the questions and proffered replies seemed to indicate a certain amount of prejudice and pre-conceived notions - and this is certainly true. The authors of this report have, some

knowledge of each of the technologies in question. While this undoubtedly impacted on the formulation of the questionnaires, it can not be stated with certainty that this was not a positive input. The <ins>numerical</ins> indication of the tabulated responses which follow do not of course reflect the convictions or prejudices of the authors. The indicated <ins>assessments</ins> of the results of the questionnaires, however, are biased by the knowledge of the authors. The distinction made above between the raw numerical indications and the "consensus" is best illuminated by the following example.

We suppose that a question was asked as follows: "The typical maximum air speed of commercial planes will be in 1990? In 2005?" We further suppose that of 26 people contacted, 14 filled out the multiple choice reply, 6 returned the questionnaire with a statement that they were unable (for one reason or another) to reply, and 6 failed to reply at all (these percentages accurately reflect the actual total response to the many questionnaires). The tabulation would then be presented as follows (there is nothing factual about this example):

Question. "typical maximum air speed" (for commercial planes) - in Mach Numbers.

< 1	1	2	3	4	5	> 5	
							Current best estimate

< 1	1	2	3	4	5	> 5	
3	8	4	1				1990 A.D.

< 1	1	2	3	4	5	> 5	
2	1	5	5	2			2005 A.D.

The above example shows blocks tabulated in units of Mach-Number as >1 1. 2, 3, 4, 5, and >5. The "current best estimate" was not requested in the questionnaire. The guess by at least one of the authors is indicated by shading. In this example it is somewhere between the first two choices, possibly Mach 0.5 to Mach 0.75. The 1990 A.D. and 2005 A.D. lines repeat the same tabulated choices, but the numerals in the respective boxes indicate the number of respondents selecting that choice. In 1990 A.D., for example, 3 chose < Mach 1, 8 chose Mach 1, 4 chose Mach 2, and 1 chose Mach 3. The vertical arrow beneath the row of boxes represents the authors' estimation of a consensus. This is obviously weighted with their own opinions in those cases where a real consensus is not markedly apparent. In the 1990 A.D. example this is shown by the selection of some number like Mach 1.5 rather than the Mach 1 at which another might have placed the "consensus" arrow. Similarly, in the 2005 A.D. example, Mach 2 is selected as a "consensus" where someone else might have located the arrow between Mach 2 and Mach 3. This last example also indicates that one of the participants did not designate a choice for 2005 A.D. since the numerals there total only 15 vice the 16 for the 1990 A.D. line. It can bear repeating that the above is a made-up example presented only to assist reading the following format and is not an actual question posed in this forecast.

6.1 Category A. ACOUSTIC-DETECTION OBSTACLE AVOIDANCE

1. "Maximum Usable Range" - in km

.1	.2	.5	1	2	5	>5	
							Current best estimate

1	.2	.5	1	2	5	>5	
			4	2			1990 A.D.

.1	.2	.5	1	2	5	>5	
				5	1	1	2005 A.D.

2a. Angular Resolution - in degrees

>5	5	1	.5	.1	<.1	
						Current best estimate

>5	5	1	.5	.1	<.1	
	2	4	1			1990 A.D.

>5	5	1	.5	.1	<.1	
	1	2	3	1		2005 A.D.

2b. Range Resolution (for range selected in 1) - in m

>10	10	5	1	<1

Current best estimate

>10	10	5	1	<1
2		2	2	1

1990 A.D.

>10	10	5	1	<1
1	1	2		3

2005 A.D.

3. "Simultaneous" range resolution and angular resolution for 200 m range - in m and degrees

Range Resolution - in m

>10	10	5	1	<1	
					Current best estimate

>10	10	5	1	<1	
	1	1	3	2	1990 A.D.

>10	10	5	1	<1	
	1		3	3	2005 A.D.

Angular Resolution - in degrees

>5	5	2	1	.5	.1	<.1	
							Current best estimate

>5	5	2	1	.5	.1	<.1	
	1	2	2	2			1990 A.D.

>5	5	2	1	.5	.1	<.1	
	1		2	4			2005 A.D.

Methods of Achievement Comments:

"multiple beams and/or electronic scanning"
"array processing and beamforming"
"parametric arrays"

6.2 Category B. ACOUSTIC - DETECTION - PORTABLE SONAR

1. "Maximum Usable Range" - in km.

.1	.2	.5	1	>1

Current best estimate

.1	.2	.5	1	>1
1	3			

1990 A.D.

.1	.2	.5	1	>1
1		3		

2005 A.D.

2. Smallest Detectable Object (for range selected in 1) - in m^2

>100	100	50	10	5	<5

Current best estimate

>100	100	50	10	5	<5
			1	1	2

1990 A.D.

>100	100	50	10	5	<5
				1	3

2005 A.D.

3. "Smallest Detectable Object" (for 100 M range) - in m^2

>50	50	10	5	1	<1

Current best estimate

>50	50	10	5	1	<1
		1	1	1	1

1990 A.D.

>50	50	10	5	1	<1
			1	1	2

2005 A.D.

Comments:

"low magnetic signature equipment is imminent"
"bionic sonar is under study"

5.3 Category D/E. ACOUSTIC - DETECTION
IMAGING/MAPPING-SCANNING

1a. "Maximum Slant Range" - in km

Current best estimate

<.5	.5	.75	1	1.5	>1.5

1990 A.D.

<.5	.5	.75	1	1.5	>1.5
	2		4	3	2

2005 A.D.

<.5	.5	.75	1	1.5	>1.5
	2			1	8

1b. "Resolution" (at range [illegible]

Current best estimate

<.1	.1	1	5	10	10

1990 A.D.

<.1	.1	.1	5	10	10
	1	5	3		1

2005 A.D.

<.1	.1	1	5	10	>10
	1	4	2	3	

2a. "Maximum Towing Speed" (for range and resolution in 1) - in knots

<2	2	5	10	>10	
					Current best estimate

<2	2	5	10	>10	
	2	2	3	4	1990 A.D.

<2	2	5	10	>10	
		2	2	6	2005 A.D.

2b. "Maximum total swath width" (for range, resolution, and towing speed selected above) - in km

<1	1	1.5	2	3	>3	
						Current best estimate

<1	1	1.5	2	3	>3	
1	2	2	3	2	1	1990 A.D.

<1	1	1.5	2	3	>3	
	3		2		4	2005 A.D.

3a. "Typical Resolution" (for 250m slant range) - in m

<.1	.1	.5	1	>.5	
					Current best estimate

<.1	.1	.5	1	>.5	
2	3	5	1		1990 A.D.

<.1	.1	.5	1	>.5	
3	4	2	1		2005 A.D.

3b. "Expected tow speed" (for 250m slant range, resolution selected above. and 500m water depth) - in knots

<2	2	5	10	>10	
					Current best estimate

<2	2	5	10	>10	
	2	2	3	3	1990 A.D.

<2	2	5	10	>10	
	2	1	2	5	2005 A.D.

4. A true quantitative mapping (actual contour elevation capability) will exist in side scan sonar systems

Yes - 7	No - 3	1990 A.D.
Yes - 8	No - 2	2005 A.D.

Negative comments - "Cost prohibitive"

- "See no way"

Methods of achievement - "Dual beam"

- "Separate integrated sensors"
- "Interferometric techniques"
- "Interferometer phase comparison"
- "Within-pulse sector-scanning"
- "Improved processing"

5. Automatic corrections will be made for:

water attenuation	Yes - 8	No - 3	1990 A.D.
	Yes - 9	No - 2	2005 A.D.
ray bending	Yes - 4	No - 7	1990 A.D.
	Yes - 7	No - 4	2005 A.D.
beam pattern	Yes - 9	No - 2	1990 A.D.
	Yes - 10	No - 1	2005 A.D.
speed	Yes - 10	No - 1	1990 A.D.
	Yes - 10	No - 1	2005 A.D.
track	Yes - 7	No - 3	1990 A.D.
	Yes - 10	No - 1	2005 A.D.
fish height	Yes - 10	No - 1	1990 A.D.
	Yes - 10	No - 1	2005 A.D.

Write-ins

Speed of Sound	Yes - 1		1990 A.D.

Methods of Achievement/Comments - "All (except for ray bending) are available today

- "Focused transducer arrays will provide multiple beam patterns"
- "Bottom composition analysis will be emphasized"
- "Massive inexpensive data processing"
- "Synthetic aperture/streamers"
- "Multiple beams/electronic focusing/ synthetic apertures"
- "The British will lead in mapping developments under government sponsorship"
- "The AN/AQS-14 is state-of-the-art today"
- "Synthetic aperture/focussing/within-pulse scanning"
- "Multibeam parametric or synthetic aperture"
- "Improved signal processing"
- "Synthetic aperture/processing"

6.4 Category I. ACOUSTIC POSITIONING

1a. "Usable Maximum Slant Range" (for Short Base Line (SBL) with single transponder) - in km

<2	2	5	10	20	>20	
						Current best estimate

<2	2	5	10	20	>20	
1	2	3	9			1990 A.D.

<2	2	5	10	20	>20	
1	1	2	8	3		2005 A.D.

1b. Range Resolution (for range selected above) - in m

Current best estimate

<1	1	5	10	20	100	>100

1990 A.D.

<1	1	5	10	20	100	>100
2	6	3	3		1	

2005 A.D.

<1	1	5	10	20	100	>100
4	6	3		1		

1c. Bearing Resolution (for range selected above) - in degrees

Current best estimate

<.5	.5	1	2	5	10	>10

1990 A.D.

<.5	5	1	2	5	10	>10
2	3	7	2	1		

2005 A.D.

<.5	.5	1	2	5	10	>10
3	6	4	1			

1d. Range Resolution (for 1 km slant range) - in m

<.1	.1	.5	1	2	5	10	>10	
								Current best estimate

<.1	.1	.5	1	2	5	10	>10	
2	1	7	5					1990 A.D.

<.1	.1	.5	1	2	5	10	>10	
2	5	6	1					2005 A.D.

1e. Bearing Resolution (for 1 km slant range) - in degrees

<.1	.1	.5	1	2	5	>5	
							Current best estimate

<.1	.1	.5	1	2	5	>5	
	2	7	5				1990 A.D.

<.1	.1	.5	1	2	5	>5	
1	4	6	2	1			2005 A.D.

2a. "Maximum Usable Edge Spacing" (for /Long Base Line (LBL) with four transponders in a square grid in 1000m deep water) - in km

	<2	2	5	10	20	>20
Current best estimate						
1990 A.D.		3	4	7	1	
2005 A.D.		3	3	3	3	1

2b. "Positional Resolution" (for LBL separation selected above) - in m

	<.1	.1	1	2	5	10	20	100	>100
Current best estimate									
1990 A.D.		1	5	6		3	1		
2005 A.D.		1	8	4	1	1			

2c. "Positional Resolution" (for LBL with four transponders in a square grid with 2 km edge spacing *in 1000 m deep water) - in m*

<.1	.1	1	2	5	10	20	>20	
								Current best estimate

<.1	.1	1	2	5	10	20	>20	
1	1	8	3	3				1990 A.D.

<.1	.1	1	2	5	10	20	>20	
2	2	7	3	1				2005 A.D.

3. Automatic corrections will be made for:

Ship's speed	Yes - 13	No - 3	1990 A.D.
	Yes - 13	No - 1	2005 A.D.
Ship's motion	Yes - 12	No - 3	1990 A.D.
	Yes - 13	No - 1	2005 A.D.
Sound speed	Yes - 15	No - 1	1990 A.D.
profile	Yes - 13	No - 1	2005 A.D.

Write-ins

transponder movements	Yes - 1	2005 A.D.
current variation	Yes - 1	2005 A.D.
acceleration	Yes - 1	1990 A.D.
ray	Yes - 1	1990 A.D.
bottom conditions	Yes - 1	1990 A.D.
depth	Yes - 1	1990 A.D.

Comments:

"LBL replies assume direct paths and surface ship positioning"
"LBL may be replaced by G.P.S."
"SBL ranges less than 50 percent of water depth"
"Customer demand will set the timetable"
"Smaller LBL spacings assume shallow surface transducer"
"Super SBL will be 'superior' development"
"Resolution was unfortunately used instead of accuracy which was desired"

Methods of Achievement:

"Matched filter or correlation techniques"
"Adaptive threshold detection"
"Master-slave transponder configurations"
"Directed array transducers in ultra-SBL"
"FFT processor in addition to present correlation processor"
"Synthetic apertures for bearing discrimination"
"Sensor improvements for corrections"
"Accurate continously collected sound speed profiles"
"Ingenuity in developing algorithms"

6.5 Category J. ACOUSTIC - COMMUNICATION/TELEMETRY

1. "Maximum usable range" - in km

<1	1	2	5	10	20	>20	
							Current best estimate

<1	1	2	5	10	20	>20	
	1			3		1	1990 A.D.

<1	1	2	5	10	20	>20	
		1		1	1	2	2005 A.D.

2. "Typical bandwidth" (for range selected above) - in kHz

<.01	.01	.1	1	10	>10	
						Current best estimate

<.01	.01	.1	1	10	>10	
			3	2		1990 A.D.

<.01	.01	.1	1	10	>10	
			1	3	1	2005 A.D.

3. "Maximum usable bandwidth" (at 1 km range) - in kHz

<.5	.5	2	5	10	>10

Current best estimate

<.5	.5	2	5	10	>10
			1	2	2

1990 A.D.

<.5	.5	2	5	10	>10
				1	4

2005 A.D.

Comments:

"Vertical telemetry only considered"
"Advances by coding for redundancy elimination and error con
"Medium characteristics are limiting factor"
"Multipath limitations will be overcome"
"Non-linear signal processing techniques might be opera
2005 A.D."
"Beamforming and/or new modulation techniques may s
multipath"
"Neitner SOFAR nor very shallow water considered"

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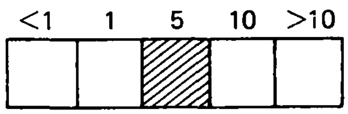
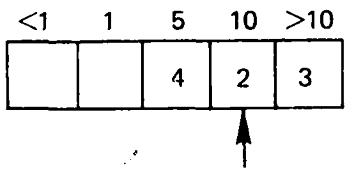
5.6 Category K. ACOUSTIC - BOTTOM PROFILING

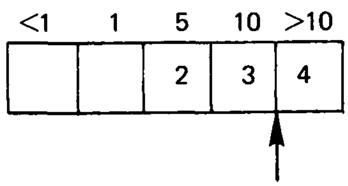
1a. "Maximum usable range" ("surface" units) - in km



Current best estimate

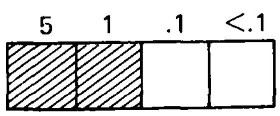


1990 A.D.

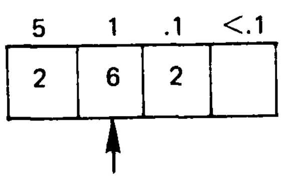


2005 A.D.

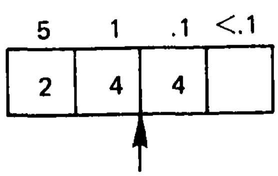
1b. "Typical vertical resolution" (for range selected above) - in m



Current best estimate

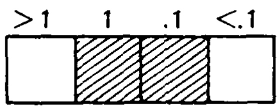


1990 A.D.

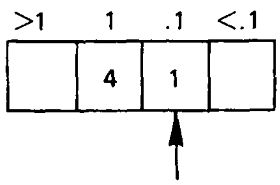


2005 A.D.

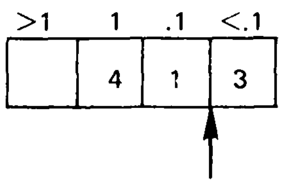
2a. "Altitude Resolution" (for deep tow) - in m



Current best estimate

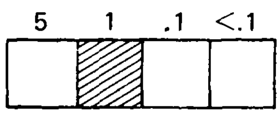


1990 A.D.

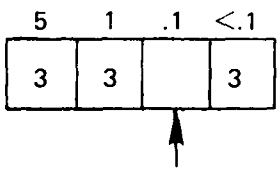


2005 A.D.

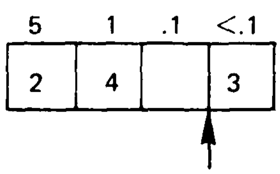
2b. "Depth Resolution" (for deep tow) - in m



Current best estimate

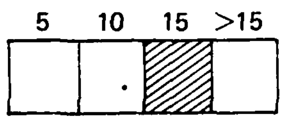


1990 A.D.

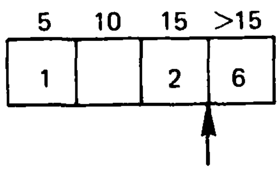


2005 A.D.

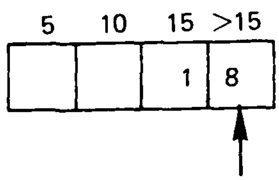
3a. Maximum usable ship speed" ("surface" units) - in kts



Current best estimate

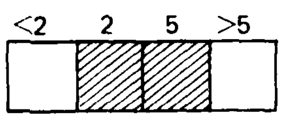


1990 A.D.

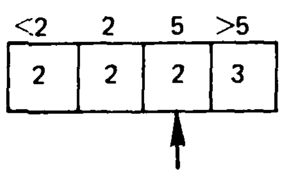


2005 A.D.

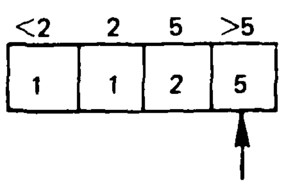
3b. "Maximum usable ship speed" (deep tow) - in kts



Current best estimate



1990 A.D.



2005 A.D.

4. Automatic corrections will be made for:

ship motion	Yes - 8	No - 1	1990 A.D.
	Yes - 8	No - 1	2005 A.D.
ship track	Yes - 6	No - 2	1990 A.D.
	Yes - 7	No - 1	2005 A.D.
ship speed	Yes - 7	No - 2	1990 A.D.
	Yes - 8	No - 1	2005 A.D.
tide	Yes - 3	No - 5	1990 A.D.
	Yes - 6	No - 2	2005 A.D.
sound speed	Yes - 6	No - 3	1990 A.D.
	Yes - 8	No - 1	2005 A.D.
other			
beam divergence	Yes - 1		2005 A.D.

Comment: Resolution used in questionnaires vice accuracy

Methods of achievement:
"Require CTD maps of world oceans"
"Heave compensation by pressure transducers and accelerometers"
"Depressor on deep tow system"
"Controlled synthetic acoustic waveform"
"Depth sounding now from 50 kt hydrofoils"
"Spread spectrum techniques and correlation processing"
"Towed systems capable of producing bathymetric charts in shallow or deep water will be available by 1990"
"Multiple beam or scanning systems deployed from a towed body"
"Narrower beams are necessary"
"Parametric array may be the answer"
"Multi-beam, selectable array to remove distortion caused by vessel motion"
"Biggest problem is, and will be, educating the public what is possible to do"
"Resolution should be separated from accuracy"

6.7 Category L. ACOUSTIC SUB-BOTTOM PROFILING

1a. "Maximum usable altitude" - in km

<.05	.05	.1	.5	>.5	
					Current best estimate

<.05	.05	.1	.5	>.5	
	1	1		5	1990 A.D.

<.05	.05	.1	.5	>.5	
	1		1	5	2005 A.D.

1b. "Maximum usable bottom penetration" (for altitude above) - in km

<.1	.1	.25	.5	1	>1	
						Current best estimate

<.1	.1	.25	.5	1	>1	
	4		1		2	1990 A.D.

<.1	.1	.25	.5	1	>1	
		3	1	1	2	2005 A.D.

1c. Definition of "resolution"

"Spatial resolution is determined by spot size - range resolution is the reciprocal of bandwidth"

"Depth accuracy requires multiple source or multiple receiver geometry and wide angle reflection/refraction recording capability-presently limited to 10% of depth"

"Ability to resolve two closely spaced reflectors - function of time-bandwidth product of separation and bandwidth"

"Ability to distinguish between two objects"

"Smallest element which can be detected and resolved"

"Ability to define the most minute change in bottom and subbottom without degrading penetration"

"Minimum separation for distinguishable reflectors of equal intensity"

"The minimum distance or separation between two adjacent geological horizons of different density that can be resolved"

1d. "Typical resolution" (for 1a, b, c) - in cm.
(this was not a multiple choice question)

Current best estimate

1	5	10	50	100

1990 A.D.

1	5	10	50	100
1		3	1	

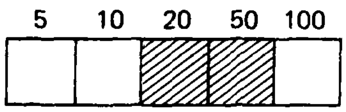
2005 A.D.

1	5	10	50	100
1	2	1	1	

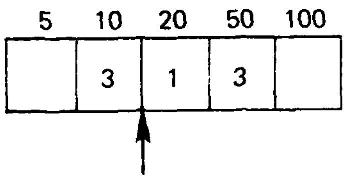
Comments: "Several centimeters range resolution for 10 meter penetration is available not"
"50cm resolution with 50m penetration should be available by 1990"
"10cm resolution should be available with 100 m penetration by 1990 and 250m penetration by 2005"
"For 100m penetration, resolution is 30cm at present, could be 10cm by 1990 and 5cm by 2005"
"Cm resolution with 1km parametric surveys by 2005"

Negative
Comments: "Resolution is basically a question of source frequency/pulse length - not a good question"

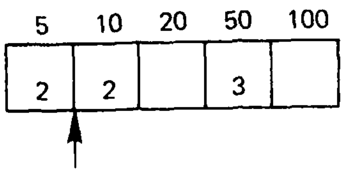
2a. "Typical resolution" (for 100m penetration) - in cm
(this was not a multiple choice question)



Current best estimate

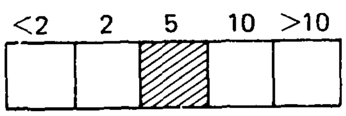


1990 A.D.

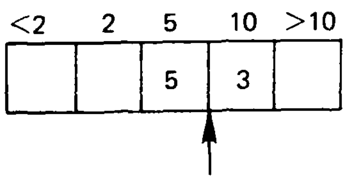


2005 A.D.

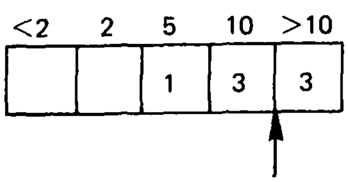
2b. "Tow speed" (for 100m penetration and resolution above) - in kts.



Current best estimate



1990 A.D.



2005 A.D.

3a. "Resolvable layer thickness" - in cm
(this was not a multiple choice question)

<5	5	10	20	50	100	
						Current best estimate

<5	5	10	20	50	100	
1	1	2	2			1990 A.D.

<5	5	10	20	50	100	
1	3	2				2005 A.D.

3b. "Detectable *acoustic impedance change*" - *in %*
(this was not a multiple choice question)

1	2	3	4	5	
					Current best estimate

1	2	3	4	5	
1	1	1		1	1990 A.D.

<.3	.3	>.3	
	2	1	2005 A.D.

Methods of achievement/comments:

"Small diameter broad bandwidth cables (fiber optic)"

"Heave compensated deep tow streamer"

"Microprocessor arrays vice optical systems"

"Parametric system"

"Lateral inhomogenetics foil signal processing attempts"

"Parametric arrays, streamer arrays, focused transducers"

"Sub bottom profilers are considered 'high resolution', 100 m or less penetration, and frequencies above 1kHz"

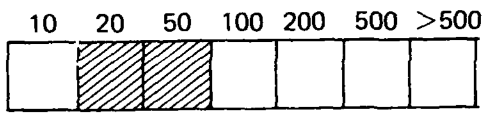
"The economics of high resolution profiling do not lend themselves to any major technological advancement - currently a waste of time and money"

"Limitations are mainly in highly variable sediment properties"

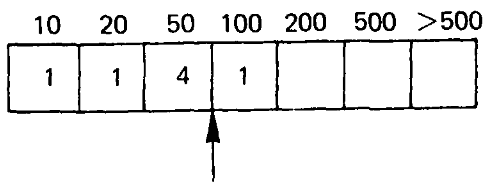
"Sub bottom profiler means a tuned transducer type system within the the Industry"

6.8 Categories O/P/Q. OPTICAL IMAGING

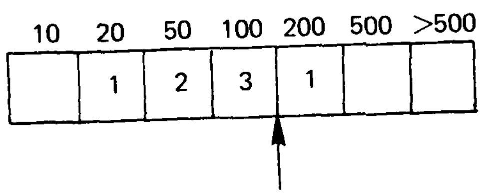
1a. "Maximum usable altitude" (for deep ocean bottom search film camera system) - in m



Current best estimate



1990 A.D.



2005 A.D.

1b. "Bottom area coverage rate" (for range above) - in km^2/hr

.2	.5	1	2	5	10	>10	
							Current best estimate

.2	.5	1	2	5	10	>10	
2	3				2		1990 A.D.

.2	.5	1	2	5	10	>10	
1	1	3				2	2005 A.D.

1c. "Typical bottom resolution" (for altitude and coverage above) - in cm

100	50	20	10	5	2	<2	
							Current best estimate

100	50	20	10	5	2	<2	
		3		1	1	2	1990 A.D.

100	50	20	10	5	2	<2	
		3		1	1	2	2005 A.D.

2a. "Maximum usable altitude" (for deep ocean bottom search quasi real-time TV system) - in m

Current best estimate

10	20	50	100	200	500	>500

1990 A.D.

10	20	50	100	200	500	>500
1	1	3	2			

2005 A.D.

10	20	50	100	200	500	>500
	1	2	3	1		

2b. "Bottom area coverage rate" (for range above) - in km^2/hr

.2	.5	1	2	5	10	>10	
							Current best estimate

.2	.5	1	2	5	10	>10	
2	2	1			2		1990 A.D.

.2	.5	1	2	5	10	>10	
1	1	3				2	2005 A.D.

2c. "Typical bottom resolution" (for altitude and coverage above) - in cm

100	50	20	10	5	2	<2	
							Current best estimate

100	50	20	10	5	2	<2	
	1	2	1	1	1	1	1900 A.D.

100	50	20	10	5	2	<2	
	1	2		2		2	2005 A.D.

3. "Angular resolution" (for film camera) - in mr.

Current best estimate

10	5	2	1	.5	.2	.1	<.1

1990 A.D.

10	5	2	1	.5	.2	.1	<.1
	1		1	2	2		1

2005 A.D.

10	5	2	1	.5	.2	.1	<.1
		1		2	3		1

4. "Angular resolution" (for TV) - in mr.

Current best estimate

10	5	2	1	.5	.2	.1	<.1

1990 A.D.

10	5	2	1	.5	.2	.1	<.1
	1	3	1	1			1

2005 A.D.

10	5	2	1	.5	.2	.1	<.1
		2	3	1			1

5. Illumination source

"Narrow angle (< 0.5°) strip source (with wide separation between source and camera)"

"Thallium iodide doped mercury vapor lights and argon laser - may require higher power"

"High energy strobes - (e.g. LIBEC) - applied engineering, not necessarily a breakthrough"

"Pulsed laser light source - need improvements in packaging and reliability"

"Optimized conventional illumination in 1990, range gated illumination and aperture in 2005"

"1500 watt sec strobe"

6. Backscatter reduction technique

"Wide separation between camera and narrow-angle strip source - if not workable, then narrow beam of light scanned and range-gated"

"Source-receiver separation for 1990 - narrow beam volume scanning for 2005"

"Gating techniques for long range"

"Range-gating techniques for both still and video systems"

"Range gated illumination and aperture system combined with image enhancement techniques"

"Large separation between camera and light"

7. Processing Techniques

"MTF compensation and contrast enhancement in near real time - a signal which has not been recorded can never be restored"

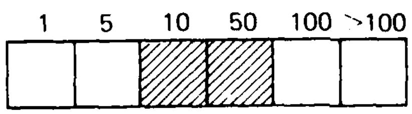
"Advanced signal processing such as developed by JPL and Tetra Tech"

"These techniques (advanced signal processing, enhancement, restoration) can not significantly increase range or resolution"

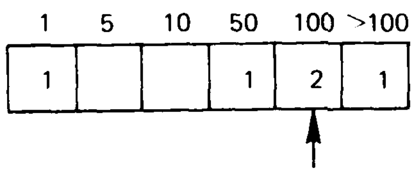
"Digital image processing to achieve image enhancement and restoration"

"High (greater than 30 db) dynamic range"

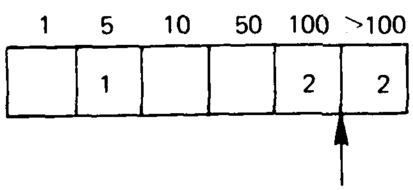
8. "Bottom area coverage rate" (for color imaging) - in m^2/hr (X100)



Current best estimate



1990 A.D.



2005 A.D.

9. Comments:

"Use Scripps advanced underwater light propagation model"

"All underwater systems should be flooded"

"Consider linear area strip camera"

"Contact NOSC"

"Contact NRL"

"R & D funding limits on improvement"

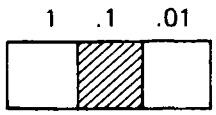
"Maximum resolution will primarily depend upon maximum attainable separation between light and camera"

6.9 Category T. MAGNETIC FIELD

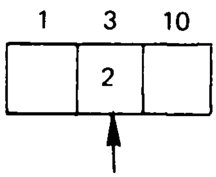
Note. Questionnaires dealt with four types of low-field (≤1nT) magnetic field measurement devices, fluxgate, proton precession, optically-pumped electron, and superconducting quantum (SQUID). Each performance factor refers to improvement over present capabilities.

I. Fluxgate magnetometers

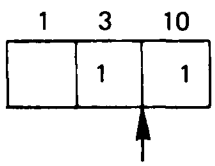
1a. Present usable sensitivity - nT



1b. Expected improvement in performance-factor



1990



2005

2. Role of signal processing in future:

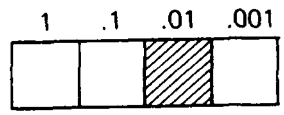
   Multielement arrays, with appropriate algorithms, will greatly enhance near field sensitivity and reduce false alarms caused by distant noise.
   Correlation techniques can increase sensitivity to specific targets.
   Time-domain as well as frequency domain analysis can be substituted for present filtering techniques.

3. Any fundamentally different sensors by 2005?
   Not based on the fluxgate principle.

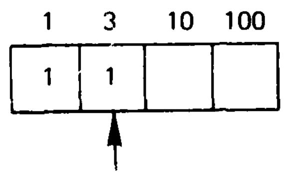
4. Further comments
   Platform motion noise is biggest limitation encountered in field use; sensitivity of the elements themselves cannot be fully exploited.

II. Proton resonance magnetometers

1a) Present usable sensitivity - nT



1b) Expected improvement in performance-factor



1990

No further improvement by 2005

2. Role of signal processing in future:

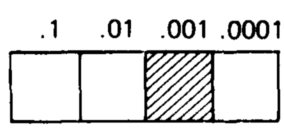
   Internal microprocessors will provide improved filtering, automated tuning, and improved timing control.
   Analog "quick look" display and other user convenience features will develop.

3. Any fundamentally different sensors by 2005?
   Probable, but no guess as to their nature.

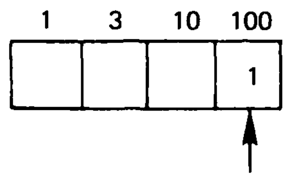
4. Further comments
   Platform noise is the limiting factor in field use; "sensor motions of less than 1/5°/sec are necessary to achieve 0.1 nT resolution."

III. Optically-pumped electron magnetometers

1a) Present usable sensitivity - nT



1b) Expected improvement in performance-factor



1990

No further improvement by 2005

2. Role of signal processing in future:

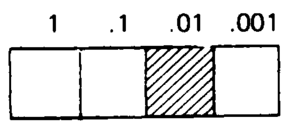
Signal processing, probably with micro-processor help, will emphasize and exploit the ability of the optical magnetometer to follow very fast (>100khz) changes in field. Heading errors will be decreased, sensitivity will increase, and information bandwidth will greatly improve.

3. Any fundamentally different sensors by 2005?
Yes, but nature unknown.

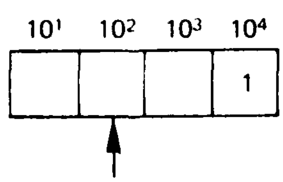
4. Further comments

IV. Superconducting Quantum (SQUID) magnetometers

1a) Present usable sensitivity - nT (X 10^{-3})



1b) Expected improvement in performance-factor.



1990

No further improvement by 2005

2. Role of signal processing in future:

   Low-noise cryogenic amplifiers will help realize inherent sensitivity of SQUID devices, but platform and environmental noise set the real limitations for field use.

3. Any fundamentally different sensors by 2005?

   Yes, perhaps based on measurement of gravitational microforces.

4. Further comments

   Magnetic sensor array imaging, used to some extent with the SQUIDs, may be interesting for future work.

APPENDIX A

Original letters sent out

SAMPLE

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C. 20375

IN REPLY REFER TO:

8420.1-33:VAD:ag
5 June 1979

Your assistance is solicited, on behalf of the Office of Research and Development, United States Coast Guard, in documenting the current status of underwater remote sensing equipment (including sensor transducer, data processing, and information transmission and display).

We believe you have or plan to develop a system with capability for underwater: a) navigation/marking/orientation, b) search/surveillance/detection, c) classification/identification, d) communication/information transfer. e) measurement/monitoring, or f) inspection/imaging. If so, please furnish details including approximate Coast Guard acquisition cost (± 30%).

To assist in your reply, sensor platforms envisioned include planes, ships, and boats as well as surface buoys and bottom and water column morrings (satellites are excluded and surface phenomena are not of current interest). Relevant sensor technologies encompass acoustic, biological, chemical, electromagnetic, force field, and mechanical (the latter including particle effects such as motion, heat, pressure, and nucleonics).

Your timely response will be most appreciated and will also permit consideration for inclusion of general specifications of your pertinent system in a report to the Coast Guard.

A second phase of this report will be a technological forecast of the expected performance parameters of underwater remote sensing technologies during the time period 1980-2005. Your comments on trends in the evolution of systems similar to yours would be of immeasurable aid in the development of this projection. Would you care to participate in this later effort?

Yours sincerely,

SAMPLE

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C. 20375

IN REPLY REFER TO:

8421-53:VAG:ag
19 November 1979

With confidence in your willingness to participate in the forecast extension phase of our report on remote underwater sensing systems for the United States Coast Guard, we are enclosing specific questions on those technologies believed appropriate to your interests.

Your answers to these questions, as well as any additional comments you might wish to make, will be extremely helpful in the formulation of a consensus concerning the status of these specific technologies in the next ten years (and with less accuracy, in the next twenty-five years).

Your replies will be kept in confidence and will not be uniquely identified in the subsequent report. It is our intent to not single out the participants (or, indeed, the non-participants) in this forecast, but rather to credit all those who cooperated in the documentation of currently available systems. We anticipate that all those who assisted in any way in this documentation will receive a copy of the final report. Further, we hope to have all references to your specific equipment checked by you, to the extent possible, before the report is printed.

Thank you for your assistance in this project. The result should be a very serviceable report. Some of the questions may appear rather naive, but please answer them all as they have been devised to promote objectivity.

Sincerely yours,

APPENDIX B

Actual questionnaires sent out for development of forecast phase of this study.

ACOUSTIC - DETECTION- OBSTACLE AVOIDANCE
SPECIFIC QUESTIONS

1. What maximum usable range will be expected for obstacle avoidance sonars in 1990?

______ 100 m
______ 200 m
______ 500 m
______ 1000 m
______ 2000 m
______ 5000 m
______ greater than 5000 m

by 2005?

______ 100 m
______ 200 m
______ 500 m
______ 1000 m
______ 2000 m
______ 5000 m
______ greater than 5000 m

2a. The angular resolution expected for obstacle avoidance sonars will be in 1990

______ greater than 5°
______ 5°
______ 1°
______ 0.5°
______ 0.1°
______ better than 0.1°

by 2005

______ greater than 5°
______ 5°
______ 1°
______ 0.5°
______ 0.1°
______ 0.1°

2b. For the range selected in (1) the range resolution expected for obstacle avoidance sonars will be in 1990

_____ greater than 10 m
_____ 10 m
_____ 5 m
_____ 1 m
_____ less than 1 m

in 2005

_____ greater than 10 m
_____ 10 m
_____ 5 m
_____ 1 m
_____ less than 1 m

3. For a range of 200 m the simultaneous range and angular resolution will be in 1990 (please select one from each column)

_____ greater than 10 m	_____ greater than 5°
_____ 10 m	_____ 5°
_____ 5 m	_____ 2°
_____ 1 m	_____ 1°
_____ less than 1 m	_____ 0.5°
	_____ 0.1°
	_____ better than 0.1°

in 2005

_____ greater than 10 m	_____ greater than 5°
_____ 10 m	_____ 5°
_____ 5 m	_____ 2°
_____ 1 m	_____ 1°
_____ less than 1 m	_____ 0.5°
	_____ 0.1°
	_____ better than 0.1°

4. In answering the above questions have you assumed the necessity for certain system improvements such as corrections for vehicle speed, water properties, or beam configuration, or the use of multiple beams, etc? If so, please amplify.

5. Would you comment on anticipated improvements in system capability by advances in signal processing techniques by 1990? by 2005?

6. Would you comment on anticipated improvements in display by 1990? by 2005?

7. Are there any other comments you wish to make?

ACOUSTIC - DETECTION- PORTABLE (HAND-HELD) SONARS

SPECIFIC QUESTIONS

1. What maximum usable range will be expected for portable (hand-held) sonars in 1990?

______ 100 m
______ 200 m
______ 500 m
______ 1000 m
______ greater than 1000 m

by 2005?

______ 100 m
______ 200 m
______ 500 m
______ 1000 m
______ greater than 1000 m

2. For the range selected in (1) the smallest detectable object will be in 1990

______ greater than 100 m^2
______ 100 m^2
______ 50 m^2
______ 10 m^2
______ 5 m^2
______ less than 5 m^2

by 2005

______ greater than 100 m^2
______ 100 m^2
______ 50 m^2
______ 10 m^2
______ 5 m^2
______ less than 5 m^2

3. For a range of 100 m the minimum detectable target size will be in 1990

______	greater than	50 m^2
______		50 m^2
______		10 m^2
______		5 m^2
______		1 m^2
______	less than	1 m^2

by 2005

______	greater than	50 m^2
______		50 m^2
______		10 m^2
______		5 m^2
______		1 m^2
______	less than	1 m^2

4. Would you comment on anticipated improvements in system capability by advances in signal processing techniques by 1990? by 2005?

5. Would you comment on anticipated improvements in display by 1990? by 2005?

6. Are there any other comments you wish to make?

ACOUSTIC - IMAGING/MAPPING - SCANNING

SPECIFIC QUESTIONS

1a. What maximum usable slant range will be typical for commercially available side scan sonars by 1990?

______	less than	500 m
______		500 m
______		750 m
______		1000 m
______		1500 m
______	greater than	1500 m.

by 2005?

______	less than	500 m
______		500 m
______		750 m
______		1000 m
______		1500 m
______	greater than	1500 m.

1b. For the slant range selected above what will be the typical resolution achieved by side scan sonars by 1990?

______	less than	10 cm
______		10 cm
______		1 m
______		5 m
______		10 m
______	greater than	10 m.

by 2005?

______	less than	10 cm
______		10 cm
______		1 m
______		5 m
______		10 m
______	greater than	10 m.

2a. For the slant range and resolution selected in question 1, considering water depths to only 500 meters, what maximum towing speed will be possible in 1990?

______	less than	2 knots
______		2 knots
______		5 knots
______		10 knots
______	greater than	10 knots.

by 2005?

______	less than	2 knots
______		2 knots
______		5 knots
______		10 knots
______	greater than	10 knots.

2b. For the selected slant range, resolution, and maximum towing speed what maximum swath width (horizontal range covered on both sides for each transmission) will be achieved in 1990?

______	less than	1000 m
______		1000 m
______		1500 m
______		2000 m
______		3000 m
______	greater than	3000 m.

in 2005?

______	less than	1000 m
______		1000 m
______		1500 m
______		2000 m
______		3000 m
______	greater than	3000 m.

3a. For a slant range of 250 m what typical resolution is expected for side scan sonars by 1990?

______	less than	10 cm
______		10 cm
______		50 cm
______		1 m
______	greater than	1 m.

by 2005?

______	less than	10 cm
______		10 cm
______		50 cm
______		1 m
______	greater than	1 m.

3b. For the slant range of 250 m and the resolution you selected in (3a), and considering water depths to only 500 meters, the tow speed expected will be in 1990?

______	less than	2 knots
______		2 knots
______		5 knots
______		10 knots
______	greater than	10 knots.

in 2005?

______	less than	2 knots
______		2 knots
______		5 knots
______		10 knots
______	greater than	10 knots.

4a. Will there be a true quantitative mapping (actual contour elevations) capability in side-scan sonar systems by 1990?

______ Yes   ______ No

by 2005

______ Yes   ______ No

4b. If so, how will it be achieved? If not, why?

5. Assuming the desirability of a true mapping capability, would you foresee the utilization of automatic corrections by 1990 for:

water attenuation	______ yes	______ no
ray bending	______ yes	______ no
beam pattern	______ yes	______ no
speed	______ yes	______ no
track	______ yes	______ no
fish height	______ yes	______ no
other (please specify)		

by 2005

water attenuation	______ yes	______ no
ray bending	______ yes	______ no
beam pattern	______ yes	______ no
speed	______ yes	______ no
track	______ yes	______ no
fish height	______ yes	______ no
other (please specify)		

6. In answering the above questions have you assumed the necessity for certain system improvements such as multiple beams, focused transducers, streamer arrays, synthetic apertures, etc.? If so, please amplify.

7. Would you comment on anticipated improvements in system capability by advances in signal processing techniques by 1990? By 2005?

8. Would you comment on anticipated improvements in display by 1990? By 2005?

9. Are there any other comments you wish to make?

1a. For a short-base-line acoustic positioning system using a single near-bottom located transponder, the usual usable maximum slant range will be in 1990

______	less than	2 km
______		2 km
______		5 km
______		10 km
______		20 km
______	greater than	20 km

in 2005

______	less than	2 km
______		2 km
______		5 km
______		10 km
______		20 km
______	greater than	20 km

1b. For the ranges selected in (1a) the range resolution expected in 1990 will be

______	less than	1 m
______		1 m
______		5 m
______		10 m
______		20 m
______		100 m
______	greater than	100 m

in 2005

______	less than	1 m
______		1 m
______		5 m
______		10 m
______		20 m
______		100 m
______	greater than	100 m

1c. For the ranges selected in (1a) the bearing resolution expected in 1990 will be

- ______ less than 0.5°
- ______ 0.5°
- ______ 1°
- ______ 2°
- ______ 5°
- ______ 10°
- ______ greater than 10°

in 2005?

- ______ less than 0.5°
- ______ 0.5°
- ______ 1°
- ______ 2°
- ______ 5°
- ______ 10°
- ______ greater than 10°

1d. For a slant range of 1 km the typical range resolution will be in 1990

- ______ less than 0.1 m
- ______ 0.1 m
- ______ 0.5 m
- ______ 1 m
- ______ 2 m
- ______ 5 m
- ______ 10 m
- ______ greater than 10 m

in 2005

- ______ less than 0.1 m
- ______ 0.1 m
- ______ 0.5 m
- ______ 1 m
- ______ 2 m
- ______ 5 m
- ______ 10 m
- ______ greater than 10 m

1e. For a slant range of 1 km the typical bearing resolution will be in 1990

_____	less than	0.1°
_____		0.1°
_____		0.5°
_____		1°
_____		2°
_____		5°
_____	greater than	5°

in 2005?

_____	less than	0.1°
_____		0.1°
_____		0.5°
_____		1°
_____		2°
_____		5°
_____	greater than	5°

2a. For a ling base line acoustic positioning system, using four near-bottom mounted transponders located in a square grid in 1000 m deep water the maximum usable edge spacing will be in 1990

_____	less than	2 km
_____		2 km
_____		5 km
_____		10 km
_____		20 km
_____	greater than	20 km

in 2005

_____	less than	2 km
_____		2 km
_____		5 km
_____		10 km
_____		20 km
_____	greater than	20 km

2b. For the transponder separations selected in (2a) the positional resolution will be in 1990

______	less than	0.1 m
______		0.1 m
______		1 m
______		2 m
______		5 m
______		10 m
______		20 m
______		100 m
______	greater than	100 m

in 2005?

______	less than	0.1 m
______		0.1 m
______		1 m
______		2 m
______		5 m
______		10 m
______		20 m
______		100 m
______	greater than	100 m

2c. For a long base line acoustic positioning system with four near-bottom mounted transponders located in a square grid with edge spacing of 2 km in a water depth of 1000 m the positional resolution will be in 1990

______	less than	0.1 m
______		0.1 m
______		1 m
______		2 m
______		5 m
______		10 m
______		20 m
______	greater than	20 m

in 2005

______	less than	0.1 m
______		0.1 m
______		1 m
______		2 m
______		5 m
______		10 m
______		20 m
______	greater than	20 m

3. Assuming the desirability of highly precise, repeatable positional data would you foresee the utilization of automatic corrections by 1990 for:

ship's speed	______	yes	______	no
ship's motion	______	yes	______	no
sound speed profile	______	yes	______	no
other (specify)				

by 2005

ship's speed	______	yes	______	no
ship's motion	______	yes	______	no
sound speed profile	______	yes	______	no
other (specify)				

4. In answering the above questions have you assumed the necessity for certain systems improvements. If so, please amplify.

5. Would you comment on anticipated improvements in system capability by advances in signal processing techniques by 1990?

by 2005?

6. Would you comment on anticipated improvements in display by 1990?

by 2005?

7. Are there any other comments you wish to make?

ACOUSTIC COMMUNICATION/TELEMETRY

SPECIFIC QUESTIONS

1. What maximum usable range will be expected for acoustic communication/telemetry systems by 1990?

______	less than	1000 m
______		1000 m
______		2000 m
______		5000 m
______		10,000 m
______		20,000 m
______	greater than	20,000 m

by 2005?

______	less than	1000 m
______		1000 m
______		2000 m
______		5000 m
______		10,000 m
______		20,000 m
______	greater than	20,000 m

2. For the maximum sypical range selected in (1) the typical bandwidth of the system will be in 1990

______	less than	10 Hz
______		10 Hz
______		100 Hz
______		1000 Hz
______		10 kHz
______	greater than	10 kHz

in 2005?

______	less than	10 Hz
______		10 Hz
______		100 Hz
______		1000 Hz
______		10 kHz
______	greater than	10 kHz

3. For a transmitter to receive separation of 1000 meters the expected maximum usable bandwidth will be in 1990

______	less than	500 Hz
______		500 Hz
______		2 kHz
______		5 kHz
______		10 kHz
______	greater than	10 kHz

by 2005?

______	less than	500 Hz
______		500 Hz
______		2 kHz
______		5 kHz
______		10 kHz
______	greater than	10 kHz

4. In answering the above questions have you assumed the necessity for certain improvements such as automatic corrections for multipath or minimization of the effects of ambient background noise through signal processing, etc. If so, please amplify.

5. Would you comment on anticipated improvements in system capability by advances in signal processing techniques by 1990? by 2005?

6. Would you comment on anticipated improvements in display by 1990? by 2005?

7. Are there any other comments you wish to make?

ACOUSTIC - ENVIRONMENTAL - BOTTOM PROFILER

SPECIFIC QUESTIONS

1a. What maximum usable range will be typical for commercially available hull-mounted or surface towed depth finders by 1990?

______	less than	1000 m
______		1000 m
______		5000 m
______		10,000 m
______	greater than	10,000 m

by 2005?

______	less than	1000 m
______		1000 m
______		5000 m
______		10,000 m
______	greater than	10,000 m

1b. What typical vertical resolution will be expected for the range selected above by 1990?

______		5 m
______		1 m
______		100 cm
______		10 cm
______	less than	10 cm

by 2005?

______		5 m
______		1 m
______		100 cm
______		10 cm
______	less than	10 cm

2a. For deep tow depth finders (pingers) the towed vehicle altitude resolution will be in 1990

______	greater than	1 m
______		1 m
______		100 cm
______		10 cm
______	less than	10 cm

in 2005?

______	greater than	1 m
______		1 m
______		100 cm
______		10 cm
______	less than	10 cm

2b. For the same deep tow depth finder (pinger) towed vehicle depth resolution will be in 1990

______		5 m
______		1 m
______		100 cm
______		10 cm
______	less than	10 cm

in 2005?

______		5 m
______		1 m
______		100 cm
______		10 cm
______	less than	10 cm

3a. The maximum usable ship speed for hull-mounted or surface-towed depth finders (pingers) will be in 1990

______		5 kts
______		10 kts
______		15 kts
______	greater than	15 kts

by 2005

______		5 kts
______		10 kts
______		15 kts
______	greater than	15 kts

3b. The maximum usable ship speed for deep towed depth finders (pingers) will be in 1990

______	less than	2 kts
______		2 kt
______		5 kts
______	greater than	5 kts

in 2005

______	less than	2 kts
______		2 kts
______		5 kts
______	greater than	5 kts

4. Assuming the desirability of absolute water depth information would you foresee the utilization of automatic corrections by 1990 for

ship motion	______ Yes	______ No
ship track	______ Yes	______ No
ship speed	______ Yes	______ No
tide	______ Yes	______ No
actual sound speed	______ Yes	______ No
other (please specify)		

by 2005?

ship motion	______ Yes	______ No
ship track	______ Yes	______ No
ship speed	______ Yes	______ No
tide	______ Yes	______ No
actual sound speed	______ Yes	______ No
other (please specify)		

5. In answering the above questions have you assumed the necessity for certain system improvements such as narrower or collimated or focused beams? Please amplify.

6. Would you comment on anticipated improvements in system capability by advances in signal processing techniques by 1990? by 2005?

7. Would you comment on anticipated improvements in display by 1990? by 2005?

8. Are there any other comments you wish to make?

ACOUSTIC - ENVIRONMENTAL - SUB-BOTTOM PROFILER

SPECIFIC QUESTIONS

1a. What maximum usable altitude will be typical for commercially available sub-bottom profilers by 1990?

______ less than 50 m
______ 50 m
______ 100 m
______ 500 m
______ greater than 500 m

by 2005?

______ less than 50 m
______ 50 m
______ 100 m
______ 500 m
______ greater than 500 m

1b. For the altitude selected in 1a. what maximum usable bottom penetration range will be typical by 1990?

______ less than 100 m
______ 100 m
______ 250 m
______ 500 m
______ 1000 m
______ greater than 1000 m

by 2005?

______ less than 100 m
______ 100 m
______ 250 m
______ 500 m
______ 1000 m
______ greater than 1000 m

1c. Considering the ambiguities in the literature concerning the definition of "resolution" would you please define your concept of this term.

1d. For your selections in (1a) and (1b) and your definition in (1c) what range of resolution would you expect to be typical for commercial systems by 1990?

by 2005?

2a. For a penetration depth of 100 m, with optimum altitude, what would you expect to be the typical range of resolution in 1990?

by 2005?

2b. For a penetration depth of 100 m and the resolution you specified in (2a) and considering water depths to only 500 m the tow speed anticipated in 1990 will be

______	less than	2 kts
______		2 kts
______		5 kts
______		10 kts
______	greater than	10 kts

in 2005?

______	less than	2 kts
______		2 kts
______		5 kts
______		10 kts
______	greater than	10 kts

3a. Would you comment on the minimum layer thickness that will be resolvable in 1990?

in 2005?

3b. Would you comment on the minimum acoustic impedance change that will be detectable in 1990?

in 2005?

4. In answering the above questions have you assumed the necessity for certain system improvements such as parametic arrays, focused transducers, streamer arrays, synthetic apertures, etc? If so, please amplify.

5. Would you comment on anticipated improvements in system capability by advances in signal processing techniques by 1990? by 2005?

6. Would you comment on anticipated improvements in display by 1990? by 2005?

7. Are there any other comments you wish to make?

OPTICAL IMAGING

SPECIFIC QUESTIONS

1a. The maximum usable altitude of a film camera system for deep ocean bottom search will be in 1990:

______ 10 m

______ 20 m

______ 50 m

______ 100 m

______ 200 m

______ 500 m

______ Greater than 500 m

in 2005:

______ 10 m

______ 20 m

______ 50 m

______ 100 m

______ 200 m

______ 500 m

______ Greater than 500 m

1b.. For the ranges selected in 1a, the square kilometers per hour covered on the bottom will be in 1990:

______ 0.2

______ 0.5

______ 1

______ 2

______ 5

______ 10

______ Greater than 10

in 2005:

______ 0.2

______ 0.5

______ 1

______ 2

______ 5

______ 10

______ Greater than 10

1c. For the altitude and coverage selected in 1a and 1b, the typical bottom resolution will be in 1990:

______ 1 m

______ 0.5 m

______ 0.2 m

______ 0.1 m

______ 5 cm

______ 2 cm

______ Better than 2 cm

in 2005:

______ 1 m

______ 0.5 m

______ 0.2 m

______ 0.1 m

______ 5 cm

______ 2 cm

______ Better than 2 cm

2a. The maximum usable altitude of a quasi real-time TV system for deep ocean bottom search will be in 1990:

______ 10 m

______ 20 m

______ 50 m

______ 100 m

______ 200 m

______ 500 m

______ Greater than 500 m

in 2005:

______ 10 m

______ 20 m

______ 50 m

______ 100 m

______ 200 m

______ 500 m

______ Greater than 500 m

2b. For the ranges selected in 2a, the square kilometers per hour covered on the bottom will be in 1990:

- ______ 0.2
- ______ 0.5
- ______ 1
- ______ 2
- ______ 5
- ______ 10
- ______ Greater than 10

in 2005:

- ______ 0.2
- ______ 0.5
- ______ 1
- ______ 2
- ______ 5
- ______ 10
- ______ Greater than 10

2c. For the altitude and coverage selected in 2a and 2b, the typical bottom resolution will be in 1990:

- ______ 1 m
- ______ 0.5 m
- ______ 0.2 m
- ______ 0.1 m
- ______ 5 cm
- ______ 2 cm
- ______ Better than 2 cm

in 2005:

- ______ 1 m
- ______ 0.5 m
- ______ 0.2 m
- ______ 0.1 m
- ______ 5 cm
- ______ 2 cm
- ______ Better than 2 cm

3. What angular resolution is expected for typical in-water film camera systems in 1990:

- ______ 10 mr
- ______ 5 mr
- ______ 2 mr
- ______ 1 mr
- ______ .5 mr
- ______ .2 mr
- ______ .1 mr
- ______ Better than .1 mr

in 2005:

- ______ 10 mr
- ______ 5 mr
- ______ 2 mr
- ______ 1 mr
- ______ .5 mr
- ______ .2 mr
- ______ .1 mr
- ______ Better than .1 mr

4. What angular resolution is expected for typical quasi real-time in-water TV systems in 1990:

- ______ 10 mr
- ______ 5 mr
- ______ 2 mr
- ______ 1 mr
- ______ .5 mr
- ______ .2 mr
- ______ .1 mr
- ______ Better than .1 mr

in 2005:

- ______ 10 mr
- ______ 5 mr
- ______ 2 mr
- ______ 1 mr
- ______ .5 mr
- ______ .2 mr
- ______ .1 mr
- ______ Better than .1 mr

5. In answering the above questions what illumination source have you assumed? If your answers require a breakthrough in illumination technology what kind have you envisioned?

6. If some backscatter-reduction technique is implied in your answers, please detail the kind, viz., scanning, range-gating, etc.

7. If advanced signal processing, enhancement, or restoration techniques are implied in your answers, please specify them and elaborate thereupon.

8. Assuming the desirability of color imaging for investigating corrosion or fatigue cracking of man-made structures underwater, the areal coverage in square meters/hr for such color imaging will be in 1990:

_____ 100

_____ 500

_____ 1000

_____ 5000

_____ 10,000

_____ Greater than 10,000

in 2005:

_____ 100

_____ 500

_____ 1000

_____ 5000

_____ 10,000

_____ Greater than 10,000

9. Please add any comments you wish to make.

MAGNETOMETERS

SPECIFIC QUESTIONS

1.a. Because of environmental noise, the superconducting quantum interference devices (SQUIDS) are usually employed in gradiometer configurations. Please indicate what you consider to be the maximum sensitivity currently achievable by real instruments.

______ nT/meter

1.b. How much improvement in performance do you expect by 1990? A factor of:

______ unity
______ 3
______ 10
______ 100

by 2005?

______ unity
______ 3
______ 10
______ 100

2. Would you comment on the role signal processing, specifically, is likely to play in achieving these advances?

3. Would you comment on possible disadvantages of having to operate the SQUID instruments at crypgenic temperatures, especially in operational situations.

4. Assuming that present magnetometer sensors of interest fall into four categories, fluxgate, proton, optically-pumped, and superconducting (SQUID), do you expect any fundamentally different sensors to appear by 1990? 2005?

5. Please make any further comments if you wish.

MAGNETOMETERS

SPECIFIC QUESTIONS

1.a. For proton magnetometers, please indicate the maximum usable sensitivity presently achievable with actual instruments, ignoring the limitations imposed by environmental noise.

______ 1 nT

______ 0.1 nT

______ 0.01 nT

______ 0.001 nT

1.b. How much improvement in performance do you expect by 1990? A factor of:

______ unity

______ 3

______ 10

______ 100

by 2005?

______ unity

______ 3

______ 10

______ 100

2. Would you comment on the role signal processing, specifically, is likely to play in achieving these advances?

3. Assuming that present magnetometer sensors of interest fall into four categories, fluxgate, proton, optically-pumped, and superconducting (SQUID), do you expect any fundamentally different sensors to appear by 1990? 2005?

4. Please make any further comments if you wish.

MAGNETOMETERS

SPECIFIC QUESTIONS

1.a. For fluxgate magnetometers, please indicate the maximum useable sensitivity presently achievable with actual instruments, ignoring the limitations imposed by environmental noise:

______ 1 nT

______ 0.1 nT

______ 0.01 nT

______ ______

1.b. How much improvement in performance do you expect by 1990? A factor of:

______ unity

______ 3

______ 10

______ 100

by 2005

______ unity

______ 3

______ 10

______ 100

2. Would you comment on the role signal processing, specifically, is likely to play in achieving these advances?

3. Assuming that the present magnetometer sensors of interest fall into four categories, fluxgate, proton, optically-pumped, and superconducting (SQUID), do you expect any fundamentally different sensors to appear by 1990? 2005?

4. Please make any further comments if you wish.

MAGNETOMETERS

SPECIFIC QUESTIONS

1.a. For proton magnetometers, please indicate the maximum useable sensitivity presently achievable with actual instruments, ignoring the limitations imposed by environmental noise.

______ 1 nT

______ 0.1 nT

______ 0.01 nT

______ 0.001 nT

1.b. How much improvement in performance do you expect by 1990? A factor of:

______ unity

______ 3

______ 10

______ 10

by 2005?

______ unity

______ 3

______ 10

______ 100

1.c. Please answer question 1.a for the optically-pumped magnetometers:

______ 0.1 nT

______ 0.01 nT

______ 0.001 nT

______ 0.0001 nT

1.d. Please answer question 1.b for the optically-pumped magnetometers by 1990:

______ unity

______ 3

______ 10

______ 100

by 2005:

______ unity

______ 3

______ 10

______ 100

2. Would you comment on the role signal processing, specifically, is likely to play in achieving these advances? Please answer for both types.

3. Assuming that present magnetometers sensors of interest fall into four categories, fluxgate, proton, optically-pumped, and superconducting (SQUID), do you expect any fundamentally different sensors to appear by 1990? 2005?

4. Please make any farther comments if you wish.

APPENDIX C

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APPENDIX D. BIBLIOGRAPHY

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